NASA-CR-197856

... STEP PHASE A VOLUME I TITLE PAGE

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IN-74-CR

42629

Experiment Title: **(Proposed title - use no acronyms)**

Stellar Interferometer Technology Experiment

Proposing Organization(s):

Space Engineering Research Center at the Massachusetts Institute of Technology (MIT)

Jet Propulsion Laboratory (JPL)

Payload Systems Incorporated (PSI)

Principal Investigator:

Professor Edward F. Crawley

Experiment Summary: **(Describe experiment, objectives, and potential benefits in 250 words or less)**

The MIT Space Engineering Research Center and the Jet Propulsion Laboratory stand ready to advance science sensor technology for discrete-aperture astronomical instruments such as space-based optical interferometers. The objective of the Stellar Interferometer Technology Experiment *(SITE)* is to demonstrate system-level functionality of a space-based stellar interferometer through the use of enabling and enhancing Controlled-Structures Technologies (CST).

SITE mounts to the Mission Peculiar Experiment Support System inside the Shuttle payload bay. Starlight, entering through two apertures, is steered to a combining plate where it is interfered. Interference requires 27 nanometer pathlength (phasing) and 0.29 arcsecond wavefront-tilt (pointing) control. The resulting 15 milli-arcsecond angular resolution exceeds that of current earth-orbiting telescopes while maintaining low cost by exploiting active optics and structural control technologies.

With these technologies, unforeseen and time-varying disturbances can be rejected while relaxing reliance on ground alignment and calibration. *SITE* will reduce the risk and cost of advanced optical space systems by validating critical technologies in their operational environment. Moreover, these technologies are directly applicable to commercially driven applications such as precision machining, optical scanning, and vibration and noise control systems for the aerospace, medical, and automotive sectors.

The *SITE* team consists of experienced university, government, and industry researchers, scientists, and engineers with extensive expertise in optical interferometry, nano-precision opto-mechanical control and spaceflight experimentation. The experience exists and the technology is mature. SITE will validate these technologies on a functioning interferometer science sensor in order to confirm definitively their readiness to be baselined for future science missions.

IN-STEP PHASE A SUMMARY FORM 1

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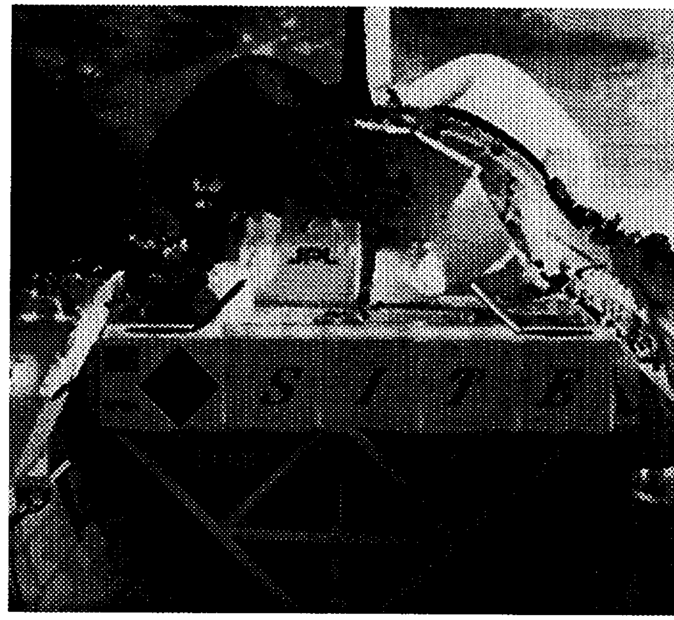
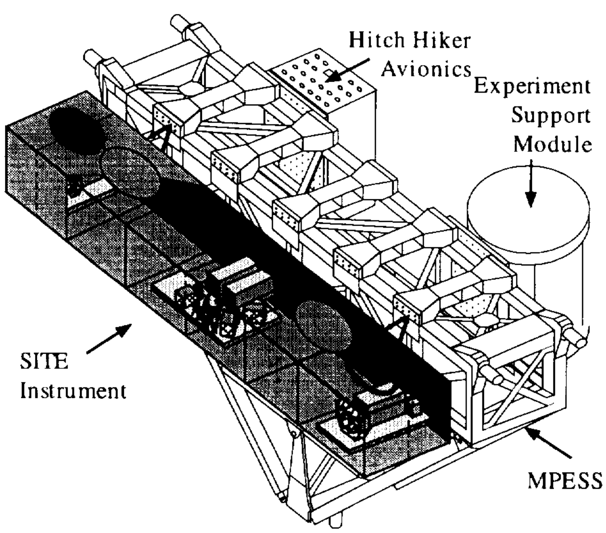
Experiment Title:

Stellar Interferometer Technology Experiment

SITE, a HitchHiker-class experiment, is a two-aperture stellar interferometer located in the Shuttle Payload Bay. It consists of three optical benches kinematically mounted inside a 4-meter precision truss structure. Starlight is collected through the apertures and an interference fringe pattern is generated. The amplitude and phase of the fringes provide the information essential for performing imaging and astrometry. To obtain precise fringe measurements, *SITE* will employ active optics for wavefront-tilt control and reactionless optical delay lines for active pathlength control. In addition, isolation and vibration suppression will attenuate vibrations caused by payload bay and internal disturbances which would otherwise blur the interference fringe pattern.





The *SITE* truss is attached to the Mission Peculiar Experiment Support System (MPESS) located across the payload bay. Signal conditioning, control and drive electronics are also mounted to the MPESS. Once on orbit, the Shuttle is aligned to acquire predetermined stellar targets. Fine alignment is accomplished by the SITE instrument itself. The experiment is controlled from the GSFC POCC.

The mission will quantify the performance and cost-benefits of the various technologies that will enable or enhance space-based interferometry. SITE will dramatically advance technology readiness in time for NASA's future interferometry missions.

Provide a diagram and description of the experiment above.

	Phase B	Phase C/D	Total (all Phases)
Cost ($K):	$1,355.4	$10,805.7	$12,161.1
Duration: (Months):	9	43	52

IN-STEP PHASE A SUMMARY FORM 2

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Experiment Title:

Stellar Interferometer Technology Experiment

Experiment Objectives (Provide concise statements of main objectives in bullet format):

- To demonstrate and quantify the system-level use of Controlled Structures Technology (CST) to enable and enhance the performance of an optical interferometer as measured by tracking stellar white light fringes.

Justification for Space Flight (bullet format):

- Flight enables the characterization of static misalignment and nonlinear dynamic effects due to gravity offload from the isolation and precision mechanisms. This characterization includes assessing the predictive fidelity of models as well as the ability to align once on orbit.
- Flight allows technology validation in the actual dynamic, vacuum, thermal, radiation and contamination environment in which future instruments will operate.
- Flight allows measurement of the undistorted starlight that future space-based interferometers will observe, serving as a metric by which the performance of the technology layers is judged.

Experiment Benefits (Also indicate benefits over competing technologies, in bullet format):

- Reduces the risk and cost of utilizing this technology in advanced optical space systems.
- Maps the cost/performance benefit of applying various technology layers to the achievement of specific mission goals.
- Allows the rejection of large unmodeled or unexpected on-orbit disturbances through active control and on-orbit redesign.
- The use of highly active optical and structural subsystems relaxes the reliance on pre-flight alignment and calibration, and the maintenance of their integrity through ground handling and launch.
- Applicable to commercially driven applications such as precision machining, optical scanning, and vibration and noise control systems for the aerospace, medical, and automotive sectors.
- Motivates and educates a new generation of students in space engineering and science.

Applications to Future Space Missions (bullet format):

- Space-based optical interferometers for astrophysical astrometry *(AIM)* and planet detection *(ASEPS-1)*:
    - Orbiting Stellar Interferometer *(OSI)*
    - Precision Optical Interferometry in Space *(POINTS)*
    - Small OSI for Narrow-Angle Astrometry with Two Apertures *(SONATA)*
- Space-based interferometry for high-resolution imaging:
    - Laser-Stabilized Imaging Interferometer *(LASII)*
    - Dilute-Lens Imager *(DLI)*
    - Separated-Spacecraft Interferometer *(SSI)*
    - High-Angular Resolution Deployable Interferometer for Space *(HARDI)*

VOLUME II: COST PLAN FOR THE STELLAR INTERFEROMETER TECHNOLOGY EXPERIMENT (SITE)

1. SUMMARY

The cost plan shown in Attachments B and C is based on the scientific and technical efforts outlined in Volume I. All amounts are in constant FY 95 dollars. Broadly stated, the work breakdown is as follows:

MIT: PI organization responsible for SITE management and systems engineering.

JPL: Co-Investigator organization responsible for optical train and external disturbance isolation.

PSI: Subcontractor responsible for instrument structural design and flight experiment integration.

This cost plan represents an official budget proposal (see attached Form 1411) with terms being effective from 2/14/95 to 8/14/95. A 6/1/95 start date is assumed.

2. COST PLAN REALISM

Because of the experience of the SITE team in developing and integrating space-qualified hardware and the recent experience of the MIT-PSI team on other Class-D modified payload development efforts such as MODE, MODE-Reflight, and MACE, we feel that the projections made are realistic. By assigning an experienced space-hardware development team to SITE, we will avoid hidden costs which frequently arise from lack of familiarity with flight hardware and/or the carrier integration process which can be quite costly and difficult to estimate. The budget represents a complete program, from requirements definition to final report, with no hidden costs.

The method used to arrive at the Cost Plan was as follows:

1. A level 6 WBS was developed and agreed upon by the three organizations.
2. Each level 3 WBS task was assigned to an organization based on expertise and previous experience.
3. Each organization developed a cost plan using a consistent approach. During this time, a dialog was maintained between all three organizations to ensure a homogenous approach and to maintain the widest possible experience base.
4. A two day meeting was held at JPL to verify and finalize the Cost Plan. Cost Plan risks (such as make/buy decisions on non flight-qualified critical items) were also identified and resolved.
5. Finally, a JPL Red Team review was conducted to assess both the technical and cost plans. The budget contained herein reflects the review results.

3. FISCAL CONTROL

SITE contractual affairs are administered through the MIT Office of Sponsored Programs using government approved procedures. MIT research accounts are audited by the Office of Naval Research and private accounting firms. The overall administration and fiscal management of the project is carried out on behalf of the Principal Investigator by the MIT Center for Space Research. Technical management and schedule control are the responsibility of the PI/Project Manager. This organization is the same as that in place for MODE, MODE-Reflight, and MACE.

4. ORGANIZATIONAL IN-KIND FUNDING

As a cost savings, the following funds will be applied to the SITE program using internal sources. By using these internal sources, a total savings of $1,138,000 will be attained.

Personnel	WBS	$/year	Total
• Prof. Crawley - 20% of salary during academic year applied to SITE project paid through internal MIT sources.	1.1, 1.3, 1.5, 2.1, 3.1	$60,000 per year for 4.3 years	$258,000
• 4 Graduate Students - Stipend & tuition paid through JPL CSI sources.	2.2, 3.1, 3.2, 3.6, 4.1, 5.2	$175,000 per year for 4 years	$700,000
• Res. Eng. IMOS Modeling - Salary paid through JPL CSI sources.	2.2	$120,000 per year for 1.5 years	$180,000

5. DIRECT LABOR RATES

The labor rates of the actual individual assigned to work on the program are used by MIT, PSI, and JPL. When new personnel are to be hired, a rate commensurate with the expected salary level is projected for that individual. The labor rates of the individuals used in this proposal may be verified by requesting information from the local DCAA or MIT Auditor. It should be noted that Prof. Crawley's salary for the academic year is not billed to the project; only a fraction of his summer salary is billed.

6. INDIRECT RATES

The MIT employee benefit and indirect expense rates are:

MIT FY	Period	EB Rate	IE Rate
1995	7/1/94- 6/30/95	43.1%	52.0%
1996	7/1/95- 6/30/96	43.5%	52.0%
1997	7/1/96- 6/30/97	43.5%	56.0%
1998	7/1/97- 6/30/98	43.5%	60.0%
1999	7/1/98- 6/30/99	43.5%	60.0%

The stated Employee Benefit rate is applied to all Salaries and Wages with the exception of undergraduate students which carries a 6.5% rate. The Indirect Expense rate is applied to the Modified Total Direct Cost (MTDC) base in accordance with OMB Circular A21. In accordance with a recent agreement between MIT and the local ONR Representative, the CSR Technical and Administrative Support and the Allocated Expenses are also removed from the MTDC Base. The rates for MIT FY 1995 are those negotiated with the Government and those for the subsequent years are estimates generally accepted for proposals within MIT. Each year the rates billed will be the approved negotiated rates for that year and may differ from the above.

7. PROGRAM CONTINGENCY

The SITE team feels that is important to specify budget contingency as an indication of the potential overrun that could occur in the development and procurement of certain high risk items. Notice that a detailed design and evaluation exercise was conducted in Phase A in order to reduce the risk of such overruns. This, in combination with the extensive experience of the SITE team, was successful in reducing development risk as indicated in the Major Equipment Table. In light of this, the JPL Red Team felt that a 10% contingency was appropriate. While this contingency is not included in the budgets summarized in Attachments B and C, a 10% increase in the budget (i.e., $1,216,100), concentrated primarily in fiscal years '96, '97, and '98, will cover all unforeseen hardware design and procurement difficulties. The maturity of the Conceptual Design Document and Implementation Plan warrants this level of contingency.

8. SUBCONTRACTS AND REVIEWS

This proposal contains the estimated cost of a proposed subcontract by MIT to Payload Systems Inc. In view of the time constraints imposed by the sponsor deadlines, MIT has conducted only a limited analysis of the subcontractor's cost proposal as part of our administrative review. A more extensive analysis will be performed by CSR and the MIT Purchasing Office after the award is made to MIT and the subcontract is negotiated.

At this time the following can be stated: Fringe Benefit rates and Indirect Cost rates have been verified with the subcontracting institution as those currently in use for its subcontracting work; Labor rates have been reviewed and appear reasonable given the proposed work; Equipment, Travel, Materials & Supplies, and other Miscellaneous Direct Costs have been reviewed and appear reasonable given the proposed work.

9. COST TABLES

The following tables contain all costing information requested in the Guidelines for In-Step Phase A Deliverables. All cost items are tied directly to the WBS and summarized by task and phase in the Attachments. All cost estimates are based on the best information of the SITE team at the time of submission, and reflect the experience of the team in designing, fabricating, certifying, and performing successful flight experiments on the Orbiter. As SITE will be a Class-D payload, commercial off-the-shelf (COTS) parts will be used where possible. We do not presently anticipate the procurement of any parts with longer lead times than 24 weeks. A detailed assessment of critical, long lead time items will be conducted early in Phase B. Cost estimates for parts and travel reflect current prices and fares.

Attachments B and C are included at the end of this Cost Volume. In addition, three tables providing additional cost detail have been provided: direct labor, materials, and travel. Costs in these supporting tables are unburdened values, so that direct comparisons with Attachments B and C can be made. Information is presented broken out by SITE partner (MIT, PSI, or JPL) and by appropriate category. Subtotals are provided for MIT and PSI since PSI is formally a subcontractor to MIT.

9.1 Direct Labor

Table II-1 describes the break out, by job category for the entire SITE program. When over 100% of a job category is listed, then more than one individual are in that category. The table only accounts for In-Step contributions. Job categories with an asterisk (*) indicate that non-In-Step funding will be used to augment the listed labor effort as described in Section 4. Tech & Admin Support is the standard rate charged by the Center for Space Research for fiscal administration. Percentages assume a constant level of staffing and do not reflect variations inherent in any flight development program.

Table II-1 Direct Labor

(* indicate that non-In-Step funding will be used to supplement the labor efforts listed in this table as described in Section 4).

		Phase B			Phase C/D			Totals	
	Employee	**%**	**Hrs.**	**Cost**	**%**	**Hrs.**	**Cost**	**Hrs.**	**Cost**
MIT	Proj. Man./PI (Summer)*	20%	48	3,435	20%	176	13,829	224	17,264
	Co-Principal Investigator	80%	1,152	24,146	80%	5,248	118,939	6,400	143,085
	Senior Scientist				35%	2,327	52,748	2,327	52,748
	Engineering Staff	24%	352	10,309	6%	400	12,280	752	22,589
	Support Staff	16%	224	3,939	35%	2,288	44,488	2,512	48,427
	Graduate Research Asst.*	200%	2,880	23,494	200%	13,120	115,634	16,000	139,128
	Tech & Admin Support			6,923			26,783		33,706
	MIT Totals:		*4,656*	*72,246*		*23,559*	*384,701*	*28,215*	*456,947*
PSI	Project Manager/Scientist	48%	691	24,561	40%	2,037	72,402	2,728	96,963
	Administrative Assistant	2%	34	516	3%	154	2,339	188	2,855
	Quality Assurance Eng.	6%	91	3,180	7%	380	13,281	471	16,461
	Electrical Engineer 1	56%	810	22,320	53%	2,962	81,608	3,772	103,928
	Electrical Engineer 2	30%	428	7,211	100%	5,758	97,008	6,186	104,219
	Integration Manager	48%	691	10,917	84%	4,689	74,082	5,380	84,999
	Mechanical Engineer 1	90%	1,290	42,135	100%	5,112	166,971	6,402	209,106
	Mechanical Engineer 2	39%	564	12,666	86%	4,834	108,556	5,398	121,221
	Software Engineer 1	52%	750	21,471	83%	4,633	132,635	5,383	154,106
	Software Engineer 2	22%	317	6,860	67%	3,742	80,982	4,059	87,842
	Technician	7%	104	1,752	100%	5,758	97,008	5,862	98,760
	PSI Totals:		*5,770*	*153,589*		*40,059*	*926,872*	*45,829*	*1,080,461*
	MIT and PSI Totals:		*10,426*	*225,835*		*63,618*	*1,311,573*	*74,044*	*1,537,408*
JPL	Manager	23%	329	12,338	40%	2759	103,462	3,088	$115,800
	Optical Engineer	100%	1442	44,702	80%	5228	162,068	6,670	$206,770
	Mechanical Engineer*	340%	4893	102,974	300%	20607	434,866	25,500	$537,840
	Electrical Engineer	66%	945	29,295	100%	7171	222,289	8,116	$251,584
	Software Engineer	43%	616	19,096	100%	7313	226,697	7,929	$245,793
	Technician	42%	600	13,200	200%	12900	283,800	13,500	$297,000
	Quality Assurance				30%	1920	57,600	1,920	$57,600
	Secretary				33%	2172	39,096	2,172	$39,096
	Administrative Assistant				17%	1086	23,892	1,086	$23,892
	JPL Totals:		*8,825*	*221,605*		*61,156*	*1,553,770*	*69,981*	*1,775,375*
	Total Program:		*19,251*	*447,440*		*124,774*	*2,865,343*	*144,025*	*3,312,783*

9.2 Major Equipment List

Table II-2 contains the major equipment costs along with a breakout describing the procurement lead time, risk category, and cost basis. All significant major items are included. Miscellaneous items (fasteners, cabling, connectors, etc.), are accounted for within each major component. A phase by phase breakout is not provided since some procurement extends across several phases.

9.3 Travel

Table II-3 describes the expected travel costs for SITE including the relevant event, the number of trips, duration, and number of people. Because it is not known which NASA center would be assigned oversight of SITE, a conservative travel estimate is presented. Obviously, if JPL is assigned contractual oversight responsibility, some of the travel costs may be deferred. Additionally, Goddard Space Flight Center will decide how much support is required by the SITE team for integration and safety reviews as part of the normal integration process. For the purposes of this budget, it was assumed that some support would be required at all major reviews, either at JSC or KSC. The SITE team will also endeavor to utilize video and teleconferencing as much as possible to reduce the travel cost of this program.

Table II-2: Major Equipment List

	Equipment	WBS	L/T	Risk	Basis	Phase	Cost
MIT	Truss Prototype	3.1.2	short	N/A	heritage (MIT Interf. Testbed)	B/C/D	175,590
	Lab Support Equipment	3.1.2	short	N/A	estimate + quote	C/D	38,950
PSI	Blueprints, Drawings, Etc.	3.7.1	short	N/A	estimate + quote	B	3,800
	Software Analysis Tools	4.3.3	short	1	quote	B	4,500
	Testing, Analysis, Vendor Eval.	2.4.3	short	1	quote	C/D	6,500
	MPESS Interface	3.1.1	short	2	estimate	C/D	13,605
	Precision Optical Bench	3.1.2	long	2	heritage (MACE/MODE)	C/D	149,250
	Thermal Control Equipment	3.1.4	long	2	estimate + quote (materials)	C/D	46,948
	Containment & Shutters	3.1.5	short	2	estimate	C/D	34,650
	Experiment Control Computer	3.5.1	short	1 to 2	heritage (MODE/MACE)	C/D	14,275
	Instrument Control Computer	3.5.2	short	1 to 2	heritage (Palomar Testbed)	C/D	71,100
	Signal Conditioning System	3.5.3	long	1 to 2	heritage (Palomar Testbed)	C/D	37,200
	Signal Amplifier System	3.5.4	long	1 to 2	heritage (MODE/MACE)	C/D	96,175
	ESM Containment	3.5.5	long	2	heritage (MODE/MACE)	C/D	29,470
	Power Distribution System	3.5.6	short	2	heritage (MODE/MACE)	C/D	46,400
	Data Handling & Storage Sys	3.5.7	long	1 to 2	heritage (MODE/MACE)	C/D	18,650
	Test Equipment and Fixtures	3.7.1	short	1 to 2	heritage (MODE/MACE)	C/D	63,050
	Transportation Containers & Hndlng	3.7.1	short	1 to 2	estimate + quote	C/D	15,109
	Power & Avionics Simulation	3.7.1	short	1	estimate	C/D	8,140
	Optical Test Equipment	3.7.1	short	1	quote	C/D	28,700
	Portable Clean Room & Supplies	3.7.1	short	1	quote	C/D	27,365
	Design & Fabrication Equip. & Supp.	3.7.1	short	1	quote	C/D	46,620
	Ground Station	3.7.2	short	1	estimate + quote	C/D	46,400
	Structure/Isolation Test Facilities	4.1.2	short	1	quote	C/D	37,500
	Accept/Cert Testing and Equip.	4.2.6	short	1	quote	C/D	127,500
	Software Analysis Tools	4.3.3	short	1	quote	C/D	36,000
	Total MIT and PSI:						*1,223,448*
JPL	Metrology Laser Prototype	3.4.3	long	N/A	estimate	B	32,453
	Metrology Laser (flight)	3.4.3	long	4	estimate	C/D	64,907
	Isolators	3.2.1		2			72,695
	Isolator Latches	3.2.2		3			98,334
	Isolation Support Equipment	3.2.1					38,944
	Siderostats (proto)	3.3.1	long	N/A	estimate + quote	B	32,453
	Siderostats (flight)	3.3.1	long	3	estimate + quote	C/D	162,267
	Alignment Mirrors	3.3.3	long	2	quote (COTS)	C/D	21,636
	Accelerometers	3.3.4	long	1	quote (COTS)	C/D	27,044
	CAD camera	3.4.4	long	2	heritage (Mars Pathfinder)	C/D	162,267
	Test Facilities Opto Mechanical	3.3.1	n/a	1	estimate + quote	C/D	178,493
	Test Facilities Optics and Detectors	3.4.1	n/a	1	estimate + quote	C/D	221,764
	Test Facilities Subsystem Integration	4.1.1	n/a	1	estimate + quote	C/D	140,631
	Beam Compressors	3.4.1	long	1	heritage (multiple missions)	C/D	21,636
	WTD Camera	3.4.4	long	3	quote (Lincoln Laboratory)	C/D	324,533
	Modulators	3.4.2	short	2	estimate	C/D	32,453
	Fast-Steering Mirror	3.3.1	short	2	quote	C/D	25,963
	Calibration Source	3.4.5	short	1	estimate	C/D	10,818
	Optical Delay Line	3.3.2		3	heritage (MPI testbed) + estimate		149,610
	Total JPL						*1,818,900*
	Total Program:						*3,042,348*

Lead Time (L/T):
long - manufacture of this item exceeds 6 weeks. short - manufacture of this item either done in-house or less than 6 weeks.

Risk:
1 - off-the-shelf hardware meets both functional and environmental requirements.
2 - standard engineering is required for component to meet functional and environmental requirements.
3 - significant design and qualification are required for component to meet environmental and functional requirements.
4 - off-the-shelf hardware is available to meet functional requirements but environmental qualification is unknown.

Basis: explanation of selections in lead time and risk columns: quote, estimate or heritage.

Table II-3: Travel

	From	To	No. of Trips	No. of People	No. of Days	Purpose	Cost
MIT Phase B	Boston	Pasadena (JPL)	3	3	2	RR/CoDr/PDR	18,200
	Boston	Wash., (HQ)	1	2	1	NAR	1,350
	Boston	Houston (JSC)	1	1	3	Phase 0/1 Safety Review	2,950
						Total MIT Phase B	22,500
MIT Phase C/D	Boston	Pasadena (JPL)	1	4	2	Integration Planning	7,136
	Boston	Pasadena (JPL)	2	4	2	Program Management	14,272
	Boston	Pasadena (JPL)	2	4	2	CDR/FRR	14,272
	Boston	Houston (JSC)	3	2	2	Integration Reviews JSC	9,819
	Boston	Houston (JSC)	4	2	2	Crew Training	13,092
	Boston	Wash., (GSFC)	3	4	2	Integration Reviews GSFC	8,992
	Boston	Orlando, (KSC)	2	2	4	Pre-Launch, Launch	5,201
	Boston	Wash., (GSFC)	1	3	14	Hardware Delivery GSFC	8,992
	Boston	Wash., (GSFC)	1	4	14	Mission Ops	14,986
	Boston	Orlando, (KSC)	1	2	3	Hardware Deintegration	5,201
	Boston	Pasadena (JPL)	3	3	4	Conferences	21,078
						Total MIT Phase C/D	123,041
PSI PhaseB	Boston	Pasadena (JPL)	3	3	2	RR/CoDr/PDR	18,200
	Boston	Wash., (GSFC, HQ)	2	2	1	NAR/Prepare Phase 0/1 SDP	2,712
	Boston	Houston (JSC)	1	3	3	Phase 0/1 Safety Review	6,780
						Total PSI Phase B	27,692
PSI Phase C/D	Boston	Pasadena (JPL)	1	4	2	Integration Planning	7,136
	Boston	Pasadena (JPL)	2	4	2	CDR/FRR	14,272
	Boston	Local Area	11	n/a	n/a	Testing	2,300
	Boston	Houston (JSC)	4	2	2	Integration Reviews JSC	13,092
	Boston	Houston (JSC)	4	2	2	Crew Training	13,092
	Boston	Houston (JSC)	2	3	5	EMI/EMC/Offgas Testing	8,006
	Boston	Hampton VA (LaRC)	4	3	14	Vibration/Thermal Testing	16,404
	Boston	Orlando, (KSC)	9	2	2	Ground Ops. and Integration	20,805
	Boston	Wash., (GSFC)	4	2	2	Integration Reviews GSFC	5,994
	Boston	Orlando, (KSC)	3	2	4	Pre-delivery, KSC Support, Launch	7,802
	Boston	Wash., (GSFC)	1	4	14	Hardware Delivery GSFC	11,989
	Boston	Houston (JSC)	1	2	14	Mission Operations JSC	6,468
	Boston	Wash., (GSFC)	1	2	14	Mission Ops	7,493
	Boston	Orlando, (KSC)	1	2	3	Hardware Deintegration	5,201
	Boston	Wash., (GSFC)	1	2	3	Hardware Recovery	4,496
						Total PSI Phase C/D	144,550
						Total MIT/PSI Phase B	50,192
						Total MIT/PSI Phase C/D	267,591
JPL Phase B	Pasadena	Boston, (MIT)	2	2		Integration/Design Reviews	9,460
						Total JPL Phase B	9,460
JPL Phase C/D	Pasadena	Boston, (PSI)	4	2	4	Electronics Interface Working Mtgs.	15,136
	Pasadena	Boston, (MIT)	4	2	4	Isolation Interface Working Mtgs.	15,136
	Pasadena	Boston, (MIT)	4	1	4	Opto-Mechanical Interface Mtgs.	8,088
	Pasadena	Boston, (MIT)	1	4	5	Flight Planning/Readiness Prep.	9,082
	Pasadena	Wash., (GSFC)	4	2	3	Integration Reviews GSFC	20,434
	Pasadena	Houston (JSC)	4	2	2	Integration Reviews JSC	20,434
	Pasadena	Wash., (GSFC)	1	3	14	Hardware Delivery GSFC	10,217
	Pasadena	Wash., (GSFC)	1	3	14	Mission Ops	10,217
						Total JPL Phase C/D	108,743
						Total Program Phase B	59,652
						Total Program Phase C/D	376,334

In general, the table shows MIT and JPL personnel supporting all managerial, design, and programmatic reviews, as well as hardware delivery, operations and recovery. They support in general only a subset of integration and training reviews. PSI personnel support all integration and safety reviews, as well as appropriate design and program meetings. PSI is also responsible for all travel costs associated with testing and delivery of the hardware.

12. ATTACHMENT B

Attachment B shows program cost in FY95 dollars for each level three WBS item for each fiscal year in each Phase. Subtotals are provided across the phases. In addition, MIT and its subcontractor PSI are shown separate from JPL since these activities would be funded separately through direct transfers from the NASA Headquarters In-Step Office. A total program summary line is also provided. Please note in each table that WBS tasks that are not conducted by that organization are omitted.

13. ATTACHMENT C

Attachment C shows the SITE budget in terms of cost categories for each level three WBS task. Again, MIT/PSI is distinguished from JPL and WBS tasks not conducted by an organization are omitted. Since MIT and PSI have different overhead structures, labor overhead is not a fixed percentage of direct labor in the MIT/PSI table. Direct labor represents salary while labor overhead includes overhead and employee benefits. While MIT does not have a fee, PSI has calculated a 9% fee which is identical to that charged on the MODE and MACE programs. JPL has a 1% fee that is imposed by the California Institute of Technology on direct labor and material costs. Due to the size of the PSI subcontract, PSI cost categories are broken out rather than lumping these costs into a single subcontractor line under MIT.

PART A RELEVANCE AND TECHNICAL MERIT

A.1 FUTURE NASA APPLICATIONS

The Stellar Interferometer Technology Experiment (*SITE*) provides direct technology validation and infusion into a variety of envisioned space-based optical interferometers. It is clear that interferometers operating in the ultraviolet, visible, and infrared wavebands represent the next great leap forward in space-based astronomy and astrophysics. As stated in the Bahcall Report, interferometry is the only known method to significantly improve (by orders of magnitude) the angular resolution of current astronomical telescopes and thereby meet several key scientific goals of the 21st century: extra-solar planet detection, the precise measurement of galactic and cosmic distance scales, measurement of stellar diameters, and resolution of close binaries. NASA Astrophysics (Code SZ) and Planetary (Code SL) Divisions share an interest in these science goals.

Code SZ is considering an Astrometric Interferometer Mission (AIM) as its next new mission start after SIRTF. The Orbiting Stellar Interferometer (OSI) at JPL and the Precision Optical Interferometer in Space (POINTS) at SAO are the leading candidates for AIM, whose science goal is to map the celestial sphere to 5 micro-arcsecond accuracy. Code SZ is considering imaging interferometers such as the Laser Stabilized Imaging Interferometer (LASII), High Angular Resolution Deployable Interferometer for Space (HARDI), the Separated Spacecraft Interferometer (SSI), and the Dilute Lens Imager (DLI) as potential follow-on missions to the Hubble Space Telescope (HST). Code SL is actively pursuing optical interferometry for extra-solar planet detection under its Astronomical Search for Extrasolar Planetary Systems (ASEPS) Program. POINTS and the Small OSI for Narrow Angle Astrometry with Two Apertures (SONATA) are leading candidates for ASEPS-1, the first space mission in the series.

Space interferometry will require a significant infusion of advanced technologies beyond those required for ground operation, due primarily to platform stability issues. Recognizing the critical enabling role that advanced technology will play in the success of space optical interferometry, Code SZ has produced, as part of its AstroTech 21 Program, a "Technology Requirements Plan for Space Interferometry Missions." *SITE* is explicitly mentioned several times in this Interferometry Technology Plan (ITP) as a system-level validation of mission-critical technology that is integrated with the schedule of other key technology development efforts.

A.2 TECHNICAL RELEVANCE TO NASA

An interferometer is fundamentally a sparse aperture optical system where small, spatially distributed collecting apertures are combined to synthesize the performance of a single, larger aperture. An optical interferometer can be used for high resolution imaging as well as extremely precise astrometry (the mapping of stellar positions in the sky). *SITE* will be the first space-based optical interferometer and will investigate the value of advanced technologies for enabling successful interferometric measurements on orbit. Specifically, *SITE* will flight validate the five highest priority interferometer component technologies (as listed in the Code SZ ITP):

I. *metrology and starlight detection systems*
II. *fine pointing and vibration isolation*
III. *active delay lines and siderostats*
IV. *quiet structures and subsystems*
V. *high fidelity integrated modeling*

Furthermore, it is the systems synthesis of these technologies on orbit that poses a greater challenge than any of the individual technologies: *SITE* will demonstrate this system functionality in the operational environment of NASA's future missions.

Interferometer technology has been aggressively pursued over the past six years by the NASA Office of Space Access and Technology (Code X) with the JPL Micro-Precision Control-Structure Interaction (CSI) Program and with MIT's USERC in Controlled Structures Technology (CST). Of the five categories listed above, items II-V are Controlled Structures Technologies. These are recognized as a critical subset since, without them, space-based interferometry will not be possible.

A principal difficulty with performing optical interferometry in space arises from structural flexibility and spacecraft disturbance sources: the optical platform can simply not be as massive and stable as ground based instruments, yet mechanical stability of 10 to 20 nm is still required. In order to retain traceability of *SITE* to the future missions that it is intended to benefit, a scaling analysis was performed to normalize the mass of *SITE* to these proposed missions.

Table A-1.: Scale of *SITE* with respect to future instruments.

Instrument	Mass (M)	# Ele (E)	Baseline (B)	M/E/B
POINTS	374 kg	4+1+3	2 m	23
OSI	1250 kg	6+1+3	7 m	18
SONATA	790 kg	2+1+3	7 m	19
DLI	2969 kg	11+1+3	25 m	8
SITE	200 kg	2+1	4 m	17

Table A-1 lists the parameters of this scaling analysis: the mass, number of concentrated elements, and baseline for four envisioned missions as well as *SITE*. Concentrated elements are relatively massive subsystems such as subapertures, combining plates, and spacecraft bus components (e.g., reaction wheels). Spacecraft buses are approximately three times the mass of these other elements. OSI has ten concentrated elements arising from its six subapertures, one combining plate, and a spacecraft bus (6+1+3). *SITE* has two subapertures, one combining plate and no bus elements (2+1). Notice that the mass, number of elements, and baselines of these missions vary by a factor of ten. However, the ratio of mass per concentrated element per baseline results in a relatively limited range of values. This ratio was determined to be a relevant discriminator because it represents an intrinsic feature of an interferometer. Since the design goal is to separate one subaperture from the others by a specified baseline, the mass with which this separation is achieved provides a basis for comparison between otherwise radically different interferometer concepts. This ratio for *SITE* has been intentionally made comparable to these envisioned missions.

SITE's technology customers are clearly NASA Codes SZ and SL. To ensure maximum leverage of this program's results, *SITE* has adopted two transfer pathways. First, the team contains a leading world expert in ground and space-based optical interferometer design, fabrication, and operation. Second, a Science Advisory Committee will be formed in Phase B consisting of the world's other leading experts, from whom membership interest has been already expressed. These two pathways ensure maximum relevance to future NASA programs.

A.3 BENEFITS OF THIS TECHNOLOGY TO NASA

SITE provides direct benefit to NASA's interferometer missions because it buys down mission risk. The benefit is systems oriented because it demonstrates that the various technologies, that have been developed and operated on the ground, work in harmony in the extreme environment of earth orbit. The single best way to demonstrate system level technology readiness is to build an actual space-based interferometer, capable of acquiring and tracking stellar interference fringes. This proves unambiguously the feasibility

1,2,3,4

Table A-2.: Relative benefits of technologies to different mission architectures.

Technology Area	Astrometry (AIM)	Orbital Imaging Interferometer	Lunar Interferometer	Multiple Spacecraft
Laser Metrology	**high**	**high**	**high**	**high**
Integrated Modeling	**high**	**high**	**high**	**high**
Vibration Isolation & Pointing	**high**	**high**	**medium**	**high**
Active Delay Lines	**high**	**medium**	**high**	**high**
Quiet Structures	**high**	**high**	**medium**	**medium**
Precision Deployment	high	high	medium	medium
Thermally Stable Optics	medium	medium	high	medium
Advanced Materials	medium	medium	medium	medium
Electric Propulsion	low	low	low	high
Contamination Prevention Systems	low	low	high	low
Ground Integration Testbeds	high	high	high	high
Flight Experiments	**high**	**high**	**high**	**high**

of space interferometry, demonstrates system integration of the critical component technologies, and quantifies each technology's contribution to the overall optical performance metric (viz., stellar fringe "visibility"). This latter feature of *SITE* (i.e., component technology characterization) is where the real engineering science lies. This knowledge will allow future mission designers to confidently perform quantitative trade, performance, and cost/benefit studies to select those component technologies which are appropriate for their particular mission needs. This is the essence of risk reduction.

In addition, the success of *SITE* will have a profound impact on reducing the cost of future interferometers by flight qualifying systems and procedures which have been identified as fundamental cost drivers in previous interferometer studies: the lack of space-qualified versions of the necessary subsystems and the lack of experience in the integration of these subsystems into a working space instrument. Finally, *SITE* will benefit a broad class of potential NASA optical interferometers, not only one or two currently planned systems. This is illustrated in Table A-2 (taken directly from the ITP), where the benefit of the relevant technologies for the different interferometer architectures is rated. The technologies that *SITE* will address are shaded.

For example, *SITE*, in developing and testing technologies for a structurally connected interferometer, will nevertheless have a major impact on future interferometer missions using multiple spacecraft or virtual structures. Many component technologies such as high speed laser metrology and active optical components will be flight qualified. More important, the essence of interferometry is the coordinated and automated interaction of many active systems with extreme accuracy. Demonstration of this technology will be a significant milestone for connected as well as unconnected interferometers.

A.4 CONTRIBUTION TO US LEADERSHIP IN SPACE

By virtue of the Hubble Space Telescope (HST), the US is already the acknowledged world leader in space-based astronomy and optical systems. In order to maintain and extend this leadership position, the US must be the first nation to fly an optical interferometer. *SITE* is a critical stepping stone toward this goal. *SITE* represents a unique collaboration between NASA Codes X and S where the technology development is driven directly by the needs of the customer on a schedule that is aligned to have maximum impact on the customer's major programs. As such, *SITE* exemplifies a new process for technology infusion that, if broadly adopted, will give the US a competitive advantage by virtue of the speed with which it can apply new space technology for near term mission payoff.

Of course, another very tangible contribution of *SITE* to US leadership in space arises from the use of *SITE* as an educational focus for the next generation of aerospace leaders. Over 20 students will work on *SITE* over the course of the project. If SERC's experience in MODE and MACE is any guide, *SITE* will prove an unparalleled motivator, attracting the best and brightest young minds.

A.5 TIMELINESS OF FLIGHT RESULTS

As explicitly mentioned in the ITP, 1999 is the need date for the system-level technology validation in space that *SITE* provides. Therefore, *SITE* will allow a timely assessment of technology readiness for the start of AIM and ASEPS-1. This puts *SITE* on an aggressive but attainable schedule. Of course, the AIM and ASEPS Programs are subject to year-to-year reviews by NASA. Such reviews are ongoing (e.g., in Code SZ this review is part of the evaluation of submissions to the New Mission Concepts NRA) and could well change the timetables shown in Figure A-1. Nonetheless, optical interferometry will play a central role in NASA's future. *SITE* will help pave the way for that future.

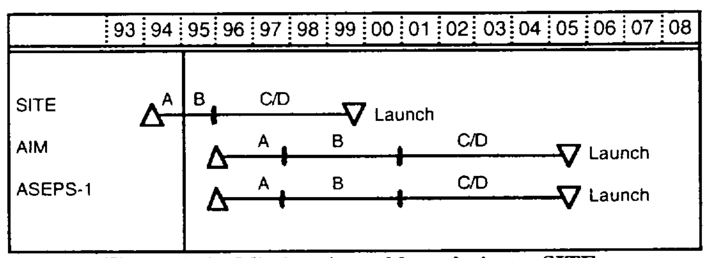

Figure A-1: Mission timetables relative to SITE

A.6 DUAL-USE, AND COMMERCIALIZATION PLAN

While the connectivity of *SITE* to future NASA missions is inherent and obvious, its applicability to broader dual-use commercial applications may not be as apparent. However there is significant commercial potential in *SITE* technology, and the *SITE* team has a plan to transfer this technology to the appropriate commercial sectors. To better understand this potential, one must consider *SITE* as a system, made up of subsystems and components. At each level there are possibilities for commercialization.

At the system level, *SITE* is a precision space-based optical system. The market for these systems is modest in size, and consists of future NASA science missions, defense observational systems, and commercial earth observing systems. In order to transfer the system-level technology, the *SITE* team includes Lockheed Missiles and Space Company, the Boeing Company, and Orbital Science Corporation. All of these companies are potential prime contractors for future government and commercial observational systems.

At the subsystem and component level, the issues which *SITE* technology addresses are significantly broader. The essence of *SITE* is a layered vibration reduction and isolation architecture which operates from low frequency through the acoustic range. Therefore, *SITE* technology can be applied to a broad class of problems. As shown in Table A-3, at the subsystem level, *SITE* includes precision metrology, precision optical control, and structural control subsystems. These subsystem technologies can be incorporated into precision machining systems, optical tooling, motion compensation for cameras and video, robotic systems and precision assembly facilities. For example, a precision micro-component manufacturing facility could use a *SITE*-like optical metrology subsystem to locate an effector, and a *SITE*-like vibration absorbing system to maintain position. Four companies are included in the *SITE* team at this subsystem level. Hughes Danbury Optical Systems is interested in adaptive optical systems for a variety of applications, as is Litton Itek Optical Systems. Honeywell is a controls company with both space and commercial business areas. They are interested in both structural control and isolation in a number of industrial applications. Boeing, in addition to being a spacecraft builder, is a manufacturer of a large number of high value commercial products, and is interested in determining if *SITE* technology is applicable to their manufacturing processes.

At the component level, the applicability of *SITE* technology is even broader. In many systems and products, from refrigerators to sports equipment to automobiles, there is unwanted sound and vibration. The *SITE* approach to penetrating this large market is to include, on the team three growing component manufacturers who aspire to build and sell to a wide market: ACX, CSA, and Midé Technologies. ACX is a small business and manufacturer of vibration and motion control systems for large volume commercial applications. CSA is a small business consultant and manufacturer of vibration isolation and damping systems. Midé Technologies is a small business and consultant specializing in nonlinear modeling and innovative mechanism design for the aerospace and automotive industries. We feel that through these three companies, *SITE* technology has the potential for penetrating a large number of eventual commercial markets.

Table A-3.: Matching of applications and industrial customers with SITE technology tiers.

Technology	Potential Applications	Companies
System: Space based optical systems	Earth sensing, laser communications, disaster relief sensing	Lockheed, OSC, Boeing
Subsystem: Metrology, precision optical, structural control	Precision machining, optical cooling, robotic alignment and guidance (welding, inspection, etc.)	HDOS, Litton, Honeywell, Boeing
Components: Isolation, active structural damping	Leveling for manufacturing, base isolation in buildings, turbine blades, environmental & industrial noise control	ACX, CSA, Midé Tech.

It is important to understand that these levels are not distinct: technology must flow from the component developers to the subsystem and system-level companies as it matures and becomes more affordable and reliable. Conversely, component developers must understand the needs of the other two levesl in order to focus their product-development efforts. As a result, the *SITE* program views the progression of advanced technology from components to system integration to be as important as targeting each of these levels individually. Therefore, a concentrated effort was made to attract companies from each level which have similar commercial interests in order to develop a healthy teaming environment.

Having identified commercial applications of *SITE* technology at the system, subsystem, and component levels, a technology commercialization plan was set in place. Letters were sent to numerous companies in each level to solicit specific interest in the *SITE* -developed technologies. The *SITE* team has received letters from the companies listed in Table A-3 which express substantial interest in participating in the *SITE* Commercialization Plan. This plan has three aspects:

Commercial Industrial Review Committee (CIRC). This Committee is composed of representatives of all the participating companies, and is analogous to a Science Advisory Committee. It will meet regularly throughout the program, and will provide feedback on commercial applications. Its functions are to keep industrial members current on the technology evolution, identify specific areas of commercialization, and provide a network of members who might propose in response to future solicitations for technology transfer and commercialization, such as the NIST, TRP, STTR, and SBIR programs.

Technology Commercialization Plan. When the CIRC identifies possible commercial pathways, an integrated product development team may be formed between the *SITE* team and industry. This team will examine the feasibility of specific commercial applications. The *SITE* team members will produce a technology assessment report and industrial members will produce a technology commercialization plan. *SITE* team members are prepared to become involved in actual product development spin-offs. Up to $20,000 of the *SITE* budget has been allocated to this activity.

Industry Subcontracts. The *SITE* team is baselined to build all components. However, early in Phase B a series of make or buy decisions will be made. Where appropriate, industrial team members will be solicited in these procurements for specific components. This will provide a hardware pathway to integrate industry members into the *SITE* team.

PART B TECHNICAL

B.1 EXPERIMENT BACKGROUND

B.1.1 Significance and Relationship to State-of-the-Art

The significance of *SITE* is that it will be the first in-space, system-level demonstration of technology that is critical to the success of stellar optical interferometry. This technology demonstration will pave the way for future missions identified in Section A.1. Optical interferometry, by combining the light from widely-separated collectors, has the ability to provide the angular resolution of a filled-aperture telescope whose diameter is equal to the separation of the collectors. Angular resolution, the ability to resolve fine detail, grows with the diameter of the aperture (for a telescope) or with the separation of the collectors (for an interferometer). The 10-m Keck Telescope on Mauna Kea is the world's largest filled-aperture optical telescope. However, ground-based optical interferometers, with baselines of many tens of meters, have been built and operated providing angular resolution exceeding that of Keck at a small fraction of the cost. Building an equivalent filled-aperture telescope providing the resolution of these interferometers would be prohibitively expensive using any foreseeable technology.

Moving to space provides the same advantages for interferometers as for conventional telescopes: the removal of the turbulent and partially opaque atmosphere. Sensitivity is greatly increased, as short exposures are no longer necessary to freeze the turbulent atmosphere. Diffraction-limited observations are possible over very wide fields of view, much greater than would be possible with any compensated imaging scheme on the ground. High dynamic range observations of faint objects next to bright ones also become possible. Finally, observations in the UV, blocked by the Earth's atmosphere, may be conducted. The success of the HST is a testament to the advantages of space for optical observations. With a baseline of 4 m, *SITE* will provide angular resolution 67% greater than that provided by the 2.4 m HST primary mirror.

The challenge of space-based interferometry is that a synthesis of several technology layers is required to achieve the necessary static and dynamic stability of the instrument. Unlike filled aperture telescopes or smaller instruments, which rely on precision internal alignment and stable thermal environments, interferometers require active optical elements to control internal optical pathlength and pointing errors, and must actively reject a range of quasistatic and dynamic environmental disturbances. An appreciation of the role that each technology fulfills is gained by examining the operation of a typical interferometer.

The principle of operation of an interferometric telescope is quite simple. A common wavefront of light from a distant star falls on two collectors (siderostats) separated by a baseline distance B (Figure B.1-1). The light from each collector passes through internal optics, which direct it towards a beam combiner, where the two light paths recombine and interfere. For the starlight fringe detector to successfully measure interference fringes, once the system is aligned, two conditions must be met: *phasing and pointing*.

The phasing condition requires that the optical pathlengths traveled in each arm of the interferometer be matched to within a few wavelengths, and stable to a few fractions of a wavelength, over the duration of each measurement (coherent integration time). Phasing is achieved by an adjustable length segment called an optical delay line (ODL) introduced into one arm. Internal metrology measures internal pathlength variations and is used to fine tune the ODL position. The pointing condition, on the other hand, requires that the beams overlap at the beamsplitter to within the diffraction limit of the siderostats. Static pointing is satisfied by internal alignment mirrors, while a combination of siderostats and fast steering mirrors (FSM) achieve dynamic pointing.

When the phasing and pointing conditions are met, the two optical paths will constructively and destructively interfere, creating peaks (I_{max}) and nulls (I_{min}) in the intensity function measured by the fringe detector. As the ODL slowly changes the length of one arm of the interferometer, a fringe pattern will emerge similar to that shown in Figure B.1-1. If the pathlengths differ by more than a few wavelengths, the two paths blur together creating an average intensity one half of the peak value (I_{mean}). Dynamic vibrations in the instrument will also lead to a blurring of the interference pattern. The science information is found in the contrast and location of the fringe pattern. The visibility function (V) defined in Figure B.1-1 is a measure of the contrast of the fringe: V=1 is ideal, whereas V=0.7 is a typical design point for an interferometer.

The *SITE* instrument closely follows the schematic outlined in Figure B.1-1, and is described in more detail in Section B.4. Briefly, *SITE* incorporates two siderostats separated by a 4 m baseline on a precision truss attached to the MPESS structure in the shuttle payload bay. A beam train incorporating various highly active technology layers steers light to the fringe detector for fringe measurement. These technology layers fall into two classifications. As discussed above, static alignment (F1), pointing control (F2), phasing control (F3) and fringe detection (F4) are fundamental to interferometer operation, regardless of whether that operation is on the ground or in space. These layers are referred to as *fundamental* technologies throughout this proposal. *SITE*, however, incorporates additional *Controlled Structures Technology (CST)* layers, because there are significant differences between ground and space operation, principally in the areas of dynamic platform stability, alignment and environmental disturbance rejection.

These fundamental and CST layers are listed in Table B.1-1. Since they represent a more detailed breakout of the five component technologies listed in the Code SZ ITP (Section A.2), they are mapped into these categories. The CST layers are briefly described below:

- *Reactionless Pointing and Phasing (C1)* mitigates the reaction forces that would otherwise exist within the instrument due to the commanded motion of delay line and steering optics. This is achieved by commanding similar inertias to move in phase and in opposing directions. This layer is an augmentation to the F2 and F3 fundamental technology layers.
- *Extended Bandwidth Control (C2)* penetrates the bandwidth, and associated performance barrier once posed by flexibility in lightweight space structures. This layer can be applied to all controlled mechanisms.
- *Isolation (C3)* is used to mitigate the transmission of vibration at the disturbance source. This is particularly powerful when transmission paths are few and well defined and disturbance sources are compact, *as they are in SITE*.

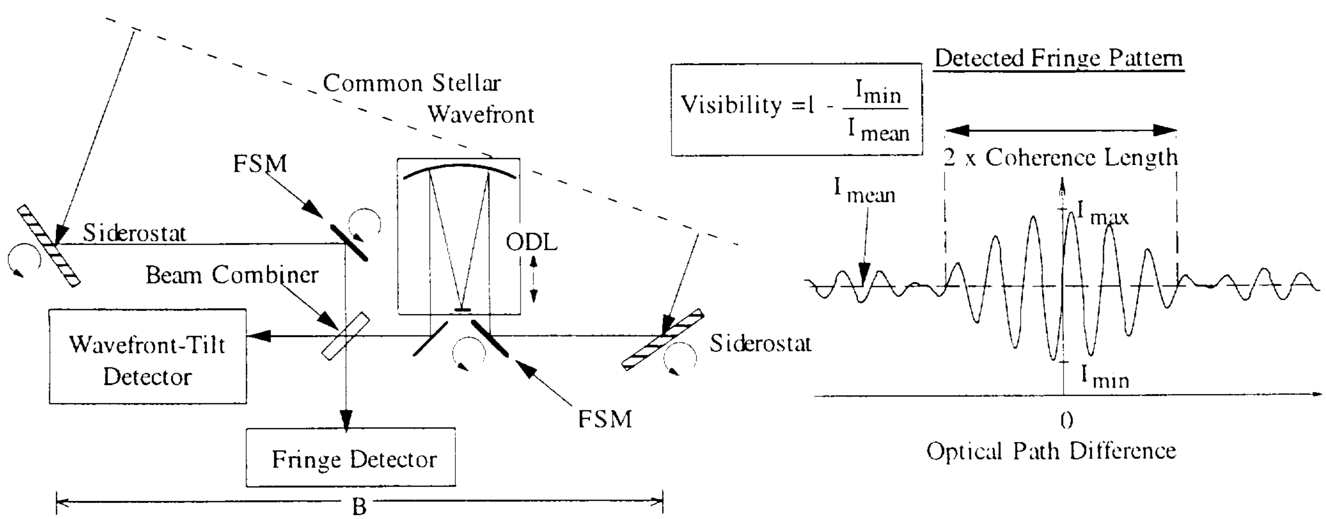

Figure B.1-1: Principles of operation of a stellar interferometer

- *Disturbance Feedforward (C4)* is used when the disturbance is measurable or known a priori, such as those caused by computer commands to articulating mechanisms. For example, attitude drift of the host carrier can be measured and fed forward to maintain instrument pointing. In addition, mechansism input commands can be shaped.
- *Vibration Suppression (C5)* attenuates disturbances along the structural transmission path, and incorporates passive and active damping in the structure and optical benches. This compliments isolation by mitigating the residual vibrations as well as those caused by sources downstream of the isolation.
- *On-Orbit Control Redesign (C6)* is performed once data is available from on orbit. This allows control designs to be fine tuned and redesigned in the event of component failures or the existence of unforeseen disturbances.
- *Quasi-static Alignment (C7)* extends static, manual alignment into the quasi-dynamic regime by using alignment mirrors which automatically compensate for beam drift introduced by thermal disturbances during instrument operation. Remember, ground systems need only maintain alignment during the atmospheric coherence time. In space, arbitrarily long observations are possible and allow increasingly sensitive measurements. Therefore, this technology is required to extend the coherent integration time beyond the time constants of thermal cycles.

On orbit, each technology layer will be activated sequentially, with newest being layered over those which are already functioning, until the fringe contrast (visibility) improves sufficiently to permit detection. The basis of the *SITE* program is to assess the cost/benefits of each layer of CST in enabling and enhancing this fringe detection.

Table B.1-1: *SITE* technology layers and their mapping to the component technology categorization from the ITP (Section A.2).

Fundamental Technology Layers		**Category**
F1	Static Alignment	I
F2	Pointing Control	II, III
F3	Phasing Control	III
F4	Fringe Detection	I
Controlled Structures Technology Layers		
C1	Reactionless Pointing and Phasing	II, III, IV
C2	Extended Bandwidth Control	IV, V
C3	Isolation	II
C4	Disturbance Feedforward	I
C5	Vibration Suppression	IV
C6	On-Orbit Control Redesign	V
C7	Quasi-static Alignment	I

B.1.2 Differences with Other Approaches

SITE differs from other space-based optical systems due to its use of highly active optical and structural subsystems. For example, the HST relied upon precision fabrication and environmental modeling and testing to ensure proper alignment and optical stability once on orbit. Once the primary mirror imperfections were identified, the passive nature of the design necessitated an expensive repair mission to attain the original performance goals.

The active subsystems in *SITE* provide an alternate approach. The active control systems complement detailed modeling and ground test with the ability to accommodate unforeseen disturbances and imperfections through on-orbit control system redesign. Lockheed provided a glimpse of the benefits of this approach through its redesign of the HST attitude control system to damp line-of-sight oscillations caused by unforeseen solar panel thermal snapping. *SITE* will go dramatically further by demonstrating the benefits that highly active subsystems can provide to future precision optical spacecraft.

The Controlled Structures Technology employed in *SITE* differs from that used in ground interferometers. On the ground, mechanism control is limited by actuator authority and sensor noise. In space, the flexibility inherent in lightweight structures motivates the use of reactionless mechanisms (C1) and external bandwidth control (C2) designed using high fidelity models of this flexibility. On the ground, platform stability is provided by massive support structures and naturally occurring damping mechanisms. In space, launch costs necessitate the use of isolation (C3), disturbance feedforward (C4), and vibration suppression (C5). Finally, on the ground control system fine tuning and optical alignment are performed manually. In space, remotely conducted on-orbit control redesign (C6) and automated and adaptive alignment (C7) are required. In essence, CST is required to replace the massive support structures and manual operation of ground instruments with highly active optical and lightweight structural subsystems for effective operation in the hostile and remote environment of space.

B.1.3 Status of Ground Research

Several ground-based interferometers have been built and operated by the *SITE* team members, as described below. The Mark III Interferometer is a long baseline (32 m) optical interferometer that operated on Mt. Wilson, CA, from 1986 to 1992. It was designed and built by members of the JPL Spatial Interferometry Group (JPL-I), then at SAO, in collaboration with MIT, NRL, and USNO. Its science observations included high accuracy wide-angle astrometric measurements, accurate stellar diameters, and binary-star orbits. The Mark III demonstrated all of the optical technologies which *SITE* will demonstrate in space: static alignment (F1), pointing control (F2), phasing control (F3), and fringe detection (F4).

The Mark III has served as the stepping stone for several other interferometers, including the Palomar Testbed Interferometer (PTI). PTI is being designed and constructed by JPL-I for installation at Palomar Mt., CA, starting in 1995. It is a 100-m baseline, dual-beam infrared interferometer designed specifically for high precision narrow-angle astrometry for the detection of exoplanets via reflex motion of their parent stars. PTI uses the same technologies as the Mark III, refined since their original application, with new technologies such as phase referencing, automated alignment (C7) and boresighting of this distributed system (F4), the latter two being particularly relevant to *SITE*. A significant amount of software was written for PTI. This includes not only servos and instrument controllers, but also high-level software for control of multiple processors, overall instrument sequencing, and user interface. The electronics and software design for *SITE* has purposely been kept very similar to PTI, allowing the porting of tested software and hardware designs, thereby reducing risk and keeping the cost down.

Intermediate between ground and space are testbeds which address platform-specific issues on a flight-like structure. Ground testbeds at JPL and MIT have been used to develop the CST layers of Table B.1-1 and to assess their impact on interferometer performance. The MicroPrecision Interferometer Testbed (MPI) was built by the JPL Control Structure Interaction Group (JPL-C) and demonstrated closed-loop operation in the lab, tracking fringes from a star simulator with the metrology, fringe detection (F4), pointing (F2) and phasing control (F3) technology layers closed. A six axis active vibration isolation mount (C3) has been built and tested on the MPI structure. Prior tests on a precursor structure, the JPL Phase B testbed, demonstrated the performance improvement possible using the CST layers of isolation (C3) and vibration suppression (C5) in addition to reactionless phasing control (C1). Special emphasis in the JPL testbeds was placed on the integration of these technology layers since interferometry requires that all of the parts play together. The integration experience from MPI, as well as Palomar and the Mark III, provides confidence that the same can be done for *SITE*.

The Interferometer Testbed (IT) at MIT incorporates a precision laser metrology system to monitor the motion of widely separated optics mounted on a flight-like truss. Focus was placed on assessing the technology layers of passive and, active vibration suppression (C5) and isolation (C3). Development tools for measurement-based structural models, finite element model refinement, and robust control synthesis (C2) were refined and matured for application to modally rich, multivariable systems. These experiences will be brought to bear on *SITE* to demonstrate the effectiveness of CST in both enabling and enhancing interferometer performance.

MIT and PSI's MACE program provides experience with on-orbit structural identification, control system redesign (C6), and disturbance feedforward (C4). These techniques will be applied to *SITE* once data is available to better characterize the on-orbit disturbance environment. In addition, the crew push-off load measurements acquired by MIT's Dynamic Load Sensors on STS-62 give MIT the most comprehensive model of this Shuttle-borne disturbance.

SITE does not represent the first collaboration between these team members: MIT, JPL-I and JPL-C have coordinated their research programs in interferometer science and technology development since 1988. The *SITE* team spans the breadth of required experience: from on-orbit disturbance environment characterization, through technology development and layering, to interferometer design and operation, and finally to spaceflight experimentation. *SITE* has assembled the appropriate team for placing the first optical interferometer in space.

B.2 METHODOLOGY AND OBJECTIVE

B.2.1. Hypothesis

Interferometer technology has reached a level of maturity where a system-level demonstration in space is now necessary to validate the technologies critical to the class of interferometer missions envisioned in the Bahcall Report. Controlled Structures Technology (CST) is required for the successful operation of a space-based interferometer. These hypotheses are reflected in the experiment objectives and methodology below.

B.2.2 Experiment Objective

The objective of *SITE* is to demonstrate and quantify the system-level use of Controlled Structures Technology to enable and enhance the performance of an optical interferometer as measured by tracking stellar white light fringes.

Spaceflight is required to demonstrate the coordinated operation of subsystems which are critical to future NASA astrometric and imaging interferometers. Flight provides access to the same undistorted stellar light that is enjoyed by HST and will be observed by future interferometers. The measurement of actual stellar light to the same precision, and for the same duration, as envisioned space interferometers will irrefutably validate the system level functionality of the technology.

Spaceflight is also required to allow evaluation of the contributions of sequential technology layering on the sensitivity of *SITE*. Flight allows validation of each technology in the actual dynamic, vacuum, thermal, radiation and contamination environment in which future interferometers will operate. All exogenous inputs and disturbances to the instrument cannot be accurately modeled (or in some cases even anticipated), nor can the impact on mission performance be evaluated based solely on analysis and ground test. The measurement and control strategies developed to enable *SITE* to adapt and compensate for these exogenous inputs can be fully evaluated only in earth orbit. Because of its size, SITE also poses a significant challenge for static alignment between ground and orbit due to gravity offload, launch vibration, and thermal effects. Flight will determine the accuracy to which models and 1-g calibrations are capable of predicting these misalignments and will allow validation of the quasi-static alignment technology layer. The evaluation of the sequential CST layers in terms of the performance metric of an actual interferometer in its operational environment also requires spaceflight.

B.2.3 Methodology

The methodology employed in the *SITE* program is to demonstrate the effectiveness of various technology layers on the performance/sensitivity of the primary detector instrument which is fundamental to all envisioned space-based interferometers. Interferometer performance will be measured, while observing different magnitude stars, as different technology layers are activated. This mapping of instrument performance as a function of stellar magnitude and technology layering will provide future mission designers with valuable guidance in selecting technologies which are most appropriate for their mission needs. The value of this design guide lies in the fact that it will have been experimentally validated, through *SITE*, in the actual mission environment.

An observation consists of first pointing the Shuttle and steering optics to place the starlight on the fringe detector, then slewing the ODLs to constructively interfere the light from each arm of the interferometer, and finally measuring the 'visibility' of the interference fringe pattern. Visibility, defined in Figure B.1-1, is the pertinent performance metric for an interferometer. Higher 'visibility' corresponds to better performance. The observation also consists of a set of structural dynamic measurements that characterize the contributions of sequentially applied technology layers to the visibility function.

The result of the *SITE* methodology is a plot like that shown in Figure B.2-1. The vertical axis is stellar magnitude, with smaller values corresponding to brighter objects, and the horizontal axis corresponds to sequential technology layering. The curve on the plot indicates the limiting stellar magnitude for which a fringe can be successfully measured at each level of technology layering. Specific layers from Table B.1-1 are shown. The *enabling* technologies are those layers that must be active in order to permit fringe detection, and the *enhancing* technologies are those that improve the visibility of the fringe measurement once it is detected. Notice that an increasing number of layers become enabling technologies as dimmer stars are observed. Alternately, the figure demonstrates what stellar magnitude observations are possible for a given combination of technologies. The white-light fringe measurements acquired during the *SITE* mission, as different component technologies are activated, will be used to create this plot and validate pre-mission predictions. Descriptions of each layer, as they apply to the *SITE* experiment, appear in the Conceptual Design Section (B.4). Assessment of the cost/benefit of each of these technologies to the performance of future interferometer missions is the basis for the *SITE* program.

B.2.4 Mission Description - Observation Test Matrix

The actual on-orbit operations are driven by the execution of the methodology described above. The mission objective is to conduct a sequence of observations, comprising an on-orbit test matrix, that provide a granularity to the design map which is sufficient to reveal performance sensitivities as well as fundamental break points associated with the application of these technologies. Therefore, the test matrix is defined by three axes: stellar magnitude, technology layering, and disturbance environment. The first two of these axes are shown in Figure B.2-1

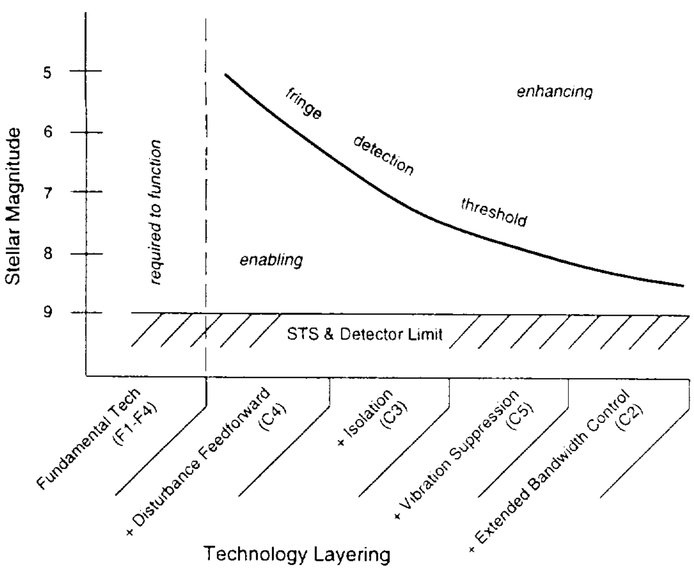

Figure B.2-1: Design guide mapping performance versus stellar magnitude and CST layering for a specific disturbance level.

Since *SITE* will not place requirements on launch inclination, altitude, or time, the stellar target list must accommodate all possible launch parameters. The Shuttle will need to point to different targets to within the field-of-view (FOV) of the *SITE* coarse pointing system (0.5°). Earth and sun-blocking attitudes will limit observation time while polar lines-of-sight allow longer integration times. Therefore, *SITE* will fringe track magnitude m_V=5, 6.5, and 8 stars. One star of magnitude 8 or brighter is found, on average, in one squared degree of the celestial sphere (Star Populations and the Solar Neighborhood). Given this density, the target star should be the brightest star in the siderostat FOV. A target selection document has been prepared and an analysis performed during Phase A demonstrated that fringes for stars dimmer than m_V=10 could not be detected, due to shuttle disturbances.

One row of the observation matrix will be filled by targeting a star of a specific magnitude and recording the improvement in visibility as successive technology layers from Table B.1-1 are applied. A row of the observation matrix corresponds to a horizontal line across the figure (constant stellar magnitude). Additional rows in the observation matrix are filled by repeating this process at different stellar magnitudes: proceeding to dimmer stars until limited by sensor noise or disturbance magnitude aboard the shuttle. Each element in the matrix will be completed at a constant shuttle disturbance level.

Many disturbance sources aboard the shuttle conspire to reduce measured fringe visibility, and as time permits, several rows of the observation matrix described above will be repeated for noisier as well as quieter disturbance conditions. There are a plethora of disturbance sources to consider. For instance, thermal gradients can cause static misalignment and become dynamic upon strain relief of thermally induced deformations (thermal snap). Observations can be conducted under low thermal gradient conditions as well as during sun-to-shade attitude maneuvers. External dynamic disturbances include crew push-off loads, the payload bay accelerations caused by vernier thruster firings in the ±1° versus ±0.1° Shuttle inertial attitude control modes, and other payload bay sources such as the Ku-Band antenna. Internal dynamic disturbances arise from the motion of opto-mechanical systems such as optical delay lines (ODLs). Although the *SITE* ODLs are mostly reactionless in their operation, they can be driven to excite motion as if they were not reactuated. Optical sources include detector noise and viewing stars in close proximity to the Moon and other bright objects. These disturbance sources can be enabled/disabled individually or in combination as these rows of the observation test matrix are repeated.

B.2.5 Flight Measurement/Requirements

Two types of flight measurement requirements are imposed to ensure that both the system and technology objectives can be achieved. From the science perspective, the normalized amplitude of the fringe pattern is referred to as the fringe visibility, and is a figure of merit for the proper operation of any interferometer. Visibility is a contrast measurement: when the peaks and fringes of the interference pattern are cleanly measured then visibility is near unity; when errors in phasing or pointing smear the fringe pattern, then visibility drops towards zero. This visibility reduction is a source of systematic error, but more significantly, corresponds to a loss of sensitivity, requiring a brighter star to achieve the same signal-to-noise ratio. Therefore, the *SITE* design must enable the measurement of a fringe from a magnitude 8 star with a visibility of 0.7.

Specific flight measurement requirements are imposed on each technology layer to ensure that its individual contribution can be quantified. Optics technology metrics are supplied by the fringe tracker for phasing, internal laser metrology system for internal phasing, the fringe detector sensor for internal alignment, the wavefront tilt detector for pointing, and accelerometers for disturbance feedforward. Transmissibility, the pertinent metric for isolation, is measured using accelerometers positioned on both the truss and MPESS sides of the isolation stage. Accelerometers located on the truss side of the isolation, along with those which provide external differential pathlength feedforward information at the siderostats, will provided data on vibration suppression. These measurements will be compared with pre-launch model predictions and allow model updating during the mission to facilitate control system redesign. All control computer input/output signals will be measured and stored. These will compliment the visibility measurements in quantifying performance as control parameters are changed.

Certain design-related technologies cannot be made switchable once on orbit -- for instance, passive thermal management, passive vibration suppression, and structural optimization -- making their contributions difficult to quantify in terms of visibility. However, thermistors will be used to corroborate thermal gradient predictions, and the active isolation stage will be used to dynamically excite the structure while on orbit to permit structural dynamic measurements.

B.2.6 Success Criteria

SITE has been designed to enable various degrees of program success even if particular components fail to function properly. This reduces susceptibility of valuable technology validation to single point failures in the instrument. Since a wide variety of intermediate experiments can be conducted, due to the ability to measure the contributions of individual technology layers, three levels of program success are defined: complete; intermediate; and minimal.

1. *SITE* will be considered a complete success once all test matrix observations are conducted and all sensors are recorded. At least one observation must provide a visibility of 0.7 for an m_V=8 star. Such results will not only achieve the requirements but will also record CST contributions as well as validate models refined during Phase C/D.
2. *SITE* will be considered an intermediate success when a white light fringe has been acquired and tracked from an actual star. This tests most of the subsystems and measures performance using a science metric. The visibility need only

be sufficient to make that fringe detectable.

3. *SITE* will be considered a minimal success once the contributions of at least two technology layers, to instrument stability, have been recorded. In the event that one arm of the interferometer fails, pointing, isolation, and vibration suppression technologies can still be assessed. By making the contributions of each technology layer independently measurable, partial mission success can still be realized.

B.3 EXPERIMENT REQUIREMENTS

1.0 The system design must be capable of measuring a visibility of V=0.7 for a magnitude 8 star with a detection bandpass centered in the visible spectrum (λ_c = 500 nm).

- 1.1 Design margin requirements allow a visibility reduction of ΔV=0.25 (V = 0.75) of which 0.15, 0.05 and 0.05 are alloted to optical, static and dynamic misalignment, respectively.
  - 1.1.1 Optical requirements include $\Delta\lambda$<80 nm detection bandpass, 98% transmissivity per surface reflection, λ/20 surface smoothness, and protected silver coatings (design provides ΔV=0.13).
  - 1.1.2 Static alignment requires 0.3 arcseconds (design provides ΔV=0.03)
  - 1.1.3 Dynamic requirements include 90% beam overlap by area, 25 nm differential pathlength RMS, and 0.286 arcseconds wavefront tilt RMS (design provides ΔV=0.04);
- 1.2 Instrument operation must acquire, track and measure the visibility of a stellar fringe, over a range of stellar magnitudes, with different combinations of CST layers.
  - 1.2.1 Fringe acquisition mode requires λ/6 (83 nm) fringe stability over ~10-100 ms (coherent integration time) without fringe tracking.
  - 1.2.2 Fringe tracking mode requires λ/20 (25 nm) RMS over 10-100 ms with fringe tracking.
  - 1.2.3 Fringe measurement mode requires λ/20 (25 nm) RMS over many coherent integration times.

2.0 Measure the individual contributions of the fundamental and CST technologies and their impact on visibility.

- 2.1 *Static Alignment* mirrors must have a range of 120 arcsec and a pointing resolution of 0.5 arcsec (F1).
- 2.2 *Pointing:* Fast steering mirrors must provide 0.01 arcsec resolution over a 500 Hz bandwidth, with a stroke twice the resolution of the siderostats. Siderostats must provide a 0.5° field-of-view and 10 arcsec resolution (F2)
- 2.3 *Phasing* requires optical delay lines with 3.5 cm stroke and 5 nm resolution (F3).
- 2.4 *Fringe detection systems* must have a signal-to-noise ratio in excess of 5 for a m_V=8 star (F4).
- 2.5 *Reactionless pointing and phasing* requires that two ODL's be used and placed in close proximity and orientation such that 90% of the internal reaction forces that would be induced by one ODL is eliminated. Low inertia FSM's will also be used (C1).
- 2.6 *Extended bandwidth control* requires the development and refinement of a high fidelity, integrated model with less than 5% error in modal parameters (C2).
- 2.7 *Vibration isolation* must provide a corner frequency variable between 2 and 20 Hz (C3).
- 2.8 *Disturbance feedforward* sensors must provide external pathlength measurements with less than 10 nm RMS noise over 0.1 to 600 Hz (C4).
- 2.9 *Vibration suppression* must augment the expected 0.3% structural damping to achieve 3% through passive and active means (C5).
- 2.10 *On-orbit control redesign* must allow on-orbit structural identification and control parameter update (C6).
- 2.11 *Quasi-static alignment* requires motorized alignment mirros with specifications identical to 2.1. In addition, an internal stimulus must be provided for boresighting the instrument. (C7)

3.0 *SITE* places particular requirements and requests upon the carrier. None of these requirements pose a significant problem with respect to manifesting opportunities or carrier capabilities. The *SITE* team understands that as a secondary payload, it cannot determine shuttle orbit, altitude, or launch time. However, *SITE* is versatile enough to accommodate a wide range of mission parameters, and should not have a problem identifying compatible primary payloads with which to share a mission.

- 3.1 *SITE* requires the Shuttle to inertially point at selected stars to an accuracy of ±1° for 30 observations of 20 minute average duration (10 hours of total on-orbit time). *SITE* requests ±0.1° inertial attitude control, coordinated Shuttle IMU and *SITE* line-of-sight calibration, Shuttle free drift, and crew quiet modes.
- 3.2 At the beginning of an observation sequence, *SITE* will require 2 to 3 orbits of sun shielding in order to sufficiently reduce thermal gradients. Calibration should be conducted at the end of this period.
- 3.3 Specific MPESS requirements and resources are listed in Table B.4-1.

B.4 CONCEPTUAL DESIGN (SYSTEM CONCEPT)

During Phase A, cost realism was identified as the highest risk to program success. Therefore, the purpose of the conceptual design is to provide sufficient hardware detail to ensure realistic cost estimates. Phase A was divided into trimesters of effort: in the first trimester, requirements were defined; subsystem concepts were enumerated; and these concepts were downselected using simplified evaluation models. In the second trimester, each selected subsystem was designed in more detail and a high-fidelity finite element model was used to evaluate the performance of the *SITE* instrument. In the third trimester, this design knowledge was captured in the form of a Conceptual Design Document (CDD) which is summarized in this section. Concurrently, costs, schedules, and the WBS were revised in order to clarify team member deliverables and understand the impact of design decisions on cost and schedule. This work was captured in an Implementation Plan, summarized in Parts C, D and the Resources Plan (Volume II). Note that the *SITE* team brings over 100 work-years of interferometry-related experience to the program, including 10 work-years of Phase A effort.

The design summarized below is split into four main sections. The first describes the overall system concept and architecture and defines the subsystems. The second discusses the options, trades, and detailed designs of each subsystem. The third presents the model used to verify that the designed system meets the performance requirements enumerated in Section B.3. The fourth describes the operations that will be conducted during the mission. Due to space limitations, this report cannot present the design to the level of detail at which it actually exists.

B.4.1 System concept

The *SITE* instrument consists of a Michelson fringe-tracking interferometer with a detection bandpass centered in the visible spectrum (λ_c = 500 nm). This instrument is mounted to the HitchHiker-C Mission Peculiar Experiment Support System (MPESS) located in the Shuttle payload bay (Figures are located on page 3). The support electronics are located in an Experiment Support Module (ESM): a sealed, pressurized container mounted on the opposite side of the MPESS from the instrument.

Neither the instrument nor the ESM violate the payload bay door closure envelope. While expendable launch vehicles and the SPARTAN free flyer were considered, the MPESS/Shuttle was selected because it provides the best combination of power, data communication, thermal control, inertial attitude control, and instrument retrievability. The MPESS-provided utilities (Table B.4-1) exceed the *SITE* requirements.

Table B.4-1: Carrier resources and *SITE* requirements.

Resource	Availability	Requirement
Power	1.4 kilowatts	1.0 kilowatt
Attitude Control	free drift, $\pm 1^\circ$, $\pm 0.1^\circ$	< ±2 degrees
Downlink	Ku-Band 1.4 Mbaud	1.0 Mbaud
Serial comm	6 ch, 1.2 kbaud ea.	1 ch
Payload control	6 ch, 24 commands	1 ch, 6 commands

Figure B.4-1 shows a cutaway drawing of the physical layout of the *SITE* instrument, an implementation of the conceptual interferometer layout of Figure B.1-1. The truss contains three optics benches and mounts to the MPESS through an isolation/latch stage. A pointing bench is located at either end while the beam-combining bench is mounted in the center. Two exterior shutters open to allow starlight to pass through the baffled ports to the two pointing benches. From there, the beams are directed to the central beam combining bench. Conceptually, the entire instrument is divided into six subsystems: structure; isolation; opto-mechanical systems; optics and metrology; support electronics; and software. Each subsystem is described below, and the relationship of each to the technology layers of Table B.1-1 is identified.

A detailed equipment list was developed in Phase A to assess a component's level of survival risk in the Shuttle payload bay during launch and on orbit. Each component has been categorized as: (1) off-the-shelf components suffice, (2) minor modifications required, (3) significant custom design required, (4) unknown. This risk is taken into account in the Resources Plan. The "(4)" designations will be eliminated early in the program through vendor evaluation, analysis, or testing.

B.4.2 Subsystem Downselect and Design

The **structure** provides passive alignment and containment for the optics benches in the presence of large thermal gradients, payload bay accelerations, and launch/landing loads. The structure subsystem is responsible for the *vibration suppression* technology layer. A downselect of structural options was performed using a trade space which spanned Truss (T) versus Plate (P) primary structures; sub-optics benches which are kinematically Isolated (I) or rigidly Fixed (F) to the structure; and three Separated (S) benches versus a Monolithic (M) optical bench. Combinations of these options were graded on traceability to future mission concepts, performance, safety, clarity of team member deliverables, and cost. The downselect favored the Truss-Isolated-Separated (TIS) and TFS concepts due primarily to performance and cost.

An analysis was performed by building NASTRAN Finite Element Models (FEMs) of each concept, all with equivalent total mass. Numerical simulations were performed with these models to identify the transmission of payload bay disturbances to differential optical pathlength difference (DPL) in nanometers RMS, the static misalignment due to gravity offload and thermal gradients, and the modal density. The TIS concept was selected because it exhibited 12% of the dynamic and 16% of the static misalignment of TFS.

The conceptual design of the structure consists of an aluminum, six-bay, internally determinant primary truss structure housing three kinematically mounted optics benches. The truss weighs 100 pounds, 24% of the instrument mass, and consists of 88 tubular struts, of 11 different lengths, resulting in a 39"x164"x25" primary structure. The TIS is enclosed by panels and shutters to provide containment as well as support for passive thermal control. While launch survivability of the individual components is critical for mission success, assured containment simplifies the Shuttle phase safety process. Before the shutters are opened, an internal stimulus is used to confirm optics train integrity.

A SERC developed thermal modeling tool was used to characterize the thermal environment as a function of shuttle orbit and attitude history. A combination of shuttle attitude and

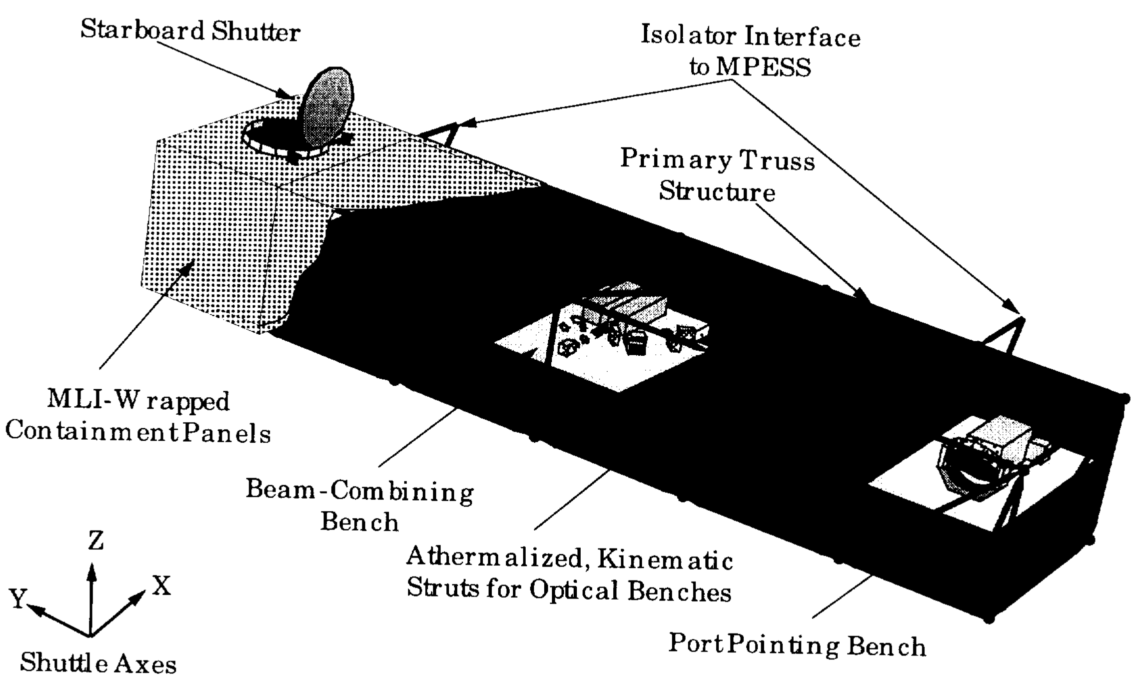

Figure B.4-1: The *SITE* instrument and subsystems.

Table B.4-2: Downselect criteria and scoring for the candidate isolation options

Isolation Options	Performance (nm RMS)			Stroke	Programmatics					
	Mag 5	Mag 8	Mag 10	(μm)	safety	cost	risk	trace	test	score
a. hard mount (none)	27	110	120	1.5	2	2	2	1	2	9
b. passive 2 Hz , ζ=0.2	1	8	100	16	1	1	1	1	0	4
c. active 2 Hz, ζ=0.2	1	8	100	16	2	0	1	1	1	5
d. passive 0.2 Hz, ζ=0.2	1	6	100	630	1	0	0	0	0	1

0 = bad, 1 = ok, 2 = good; metric = λ/20 = 27 nm rms

passive insulation was found that limited the range of temperature changes on the main truss to less than 2 degrees Kelvin during any orbit, with a maximum temperature difference across the structure also less than 2 degrees at any one time. Resulting thermal deformations were calculated using the NASTRAN model. The stroke of the active alignment system was designed to compensate for this thermal expansion since an aluminum truss was selected over one made of more stable graphite epoxy due to cost.

The optical benches will be further isolated from the structure by athermalized struts and secondary insulation. These benches will be stabilized to -10 degrees Celsius by heaters and cold-biased radiators connected to the benches with thermal straps. This particular temperature represents a tradeoff between enhancing optical sensor performance and remaining within the operating range of the opto-mechanical actuators.

The **isolation subsystem** connects the structure to the MPESS and is responsible for providing the *isolation* technology layer during observations on orbit. This subsystem must accommodate opposing requirements: during instrument operation the isolation layer must be mechanically soft to attenuate vibration transmission from the MPESS to the structure, yet be stiff at low frequencies in order to track the shuttle attitude motions. Also, the carrier requires the isolation stage to provide high stiffness during launch (>35 Hz).

A trade study was conducted to determine the degree of isolation required for *SITE*. Table B.4-2 lists the downselect criteria and the four options studied: (a) hardmount with 35 Hz corner frequency, (b) passive mount (latch released) to 2 Hz corner, (c) active softening from hardmount to 2 Hz corner, and (d) passive release to 0.2 Hz corner frequency. A NASTRAN model of the *SITE* instrument was used to determine the transmission of MPESS accelerations (derived from the Smart Acceleration Measurement System, or SAMS, data from STS-52 and STS-62) to the optical performance metric of *SITE*. The performance, measured in nanometers RMS motion of differential optical pathlength (DPL), affects the visibility function introduced earlier: RMS values below 30 nm, for example, lead to good fringe visibility. It was assumed that all prior technology layers (Table B.1-1) were enabled.

Table B.4-2 illustrates that isolation performance is a function of stellar magnitude -- a result which can be appreciated given the interactions between the isolator and the ODL and pointing control bandwidths, which themselves are functions of stellar magnitude. Options were ranked also in terms of mechanical stroke (less is desirable) and in terms of programmatic issues (high score is desirable). From these configurations, option (c) was selected because it performed better than (a) while exhibiting fewer programmatic problems than (d). Option (b) requires expensive mass offload devices for ground testing. Option (c) also provides on-orbit tuning of the corner frequency of the isolation technology layer.

All together, *SITE* will employ six active voice-coil isolator struts utilizing local feedback for softening and tuning (see Figure B.4-2). It was found that the isolator struts could not simultaneously satisfy launch stiffness requirements and be actively softened to 2 Hz corner frequency. Due to this constraint, option (c) was modified: each strut will be latch released on orbit to a 14 Hz corner frequency and then actively softened to 2 Hz. Separate devices will be used to provide the functions of isolation and latching. Three 2 degree-of-freedom latches provide launch and landing lock; three additional latches provide redundancy. It is understood that the latch mechanisms must be reliable in order to satisfy carrier concerns.

In contrast with the isolation, the **opto-mechanical and optics and metrology subsystems** isolate the performance metric from structural vibrations. These subsystems combine starlight, collected through the two apertures, to detect and track the white-light interference fringe with high visibility. Since the *SITE* team has built several such systems, the downselect focused on optical layouts and alignment. Eight layouts were considered which differed in the placement and orientation of key optical subsystems. Each was then qualitatively judged on sensitivity of beam overlap to static misalignment, the number of optical elements introducing wavefront distortion and tilt, degree of photometric symmetry, compactness, modularity, ease of alignment, etc. The layout shown in Figure B.4-3 was chosen because it has few beam folds near the siderostats (thereby reducing sensitivity to beam misalignment) and maintains high photometric symmetry. By trading off compactness in favor of high modularity, it promotes multi-team subsystem integration. This layout combines the starlight at an acute angle to minimize polarization effects and actuated static alignment mirrors increase alignability between the benches. The optical delay lines are paired to provide reactionless operation. This overall design is backward traceable to the Mark III.

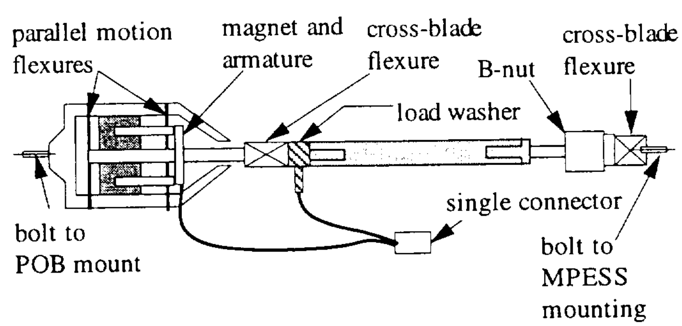

Figure B.4-2: Diagram of a single isolator strut

The optical subsystem itself may be divided into five functional areas corresponding to the technology layers listed in Table B.1-1: 1) internal alignment (F1, C7), 2) metrology and fringe detection (F4), 3) coarse acquisition and fine pointing (F2), 4) optical pathlength control (F3, C1), and 5) disturbance feedforward (of external pathlength motion) (C4). To provide for coarse-acquisition and pointing, *SITE* relies on the attitude control system of the Shuttle to point to the star within a ±1° pointing deadband. Each siderostat folds the starlight 90° into its respective beam compressor (3 to 1). After compression, 10% of the beam is directed by a beamsplitter (BS) toward the coarse acquisition detector (CAD) while the rest of the beam continues on to the beam-combining bench.

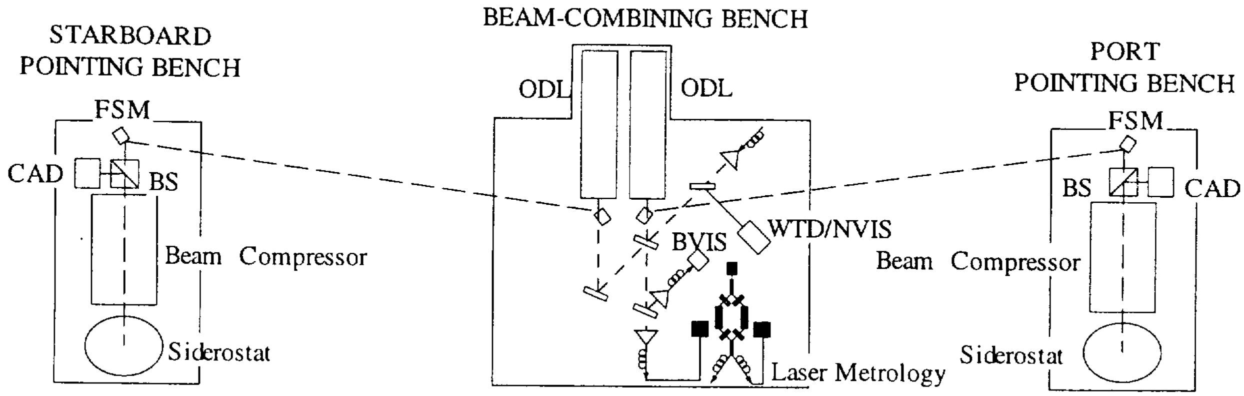

Figure B.4-3: *SITE* optical layout

The CAD is a 512x512, 50-frame/sec, 0.5° FOV CCD camera which employs a bright object centroiding algorithm to boresight the target star. The siderostat positions the stellar image on the CAD so that it will be within the narrower FOV of the wavefront-tilt detector (WTD): a 2.9 kiloframe/sec, 64x64 CCD camera. Once the WTD has locked onto the star, the CAD is no longer used and the siderostat is slewed to keep the fast-steering mirrors (FSM) within their dynamic range. The FSMs reduce any residual beam jitter and correct for wavefront tilt using the scheme employed in the Mark III which separates the stellar beam into a central core for the metrology beam, an inner annulus for the science beam, and an outer annulus for the fine-tracking beams. When the science beams are parallel, their respective fine-tracking beams fall on two pre-determined locations on the WTD.

SITE controls differential pathlength (DPL) using two movable optical delay lines (ODLs). Each ODL is a cat's eye retroreflector consisting of a parabolic mirror which focuses the collimated stellar beam onto a small flat mirror mounted on a 2-stage, 40-μm stroke piezoelectric actuator. Also, larger displacements are obtained by actuating the cat's eye retroreflector with a 1-mm stroke voice coil. The entire assembly can be translated through a 3.5 cm stroke using a lead screw actuator. Using identical ODLs in each arm maintains photometric symmetry and reactionless operation. In order to measure changes in the internal DPL, *SITE* will use an infrared laser interferometer which measures displacements along the central core of the science light path and retroreflects off corner cubes mounted on each siderostat. External DPL is estimated by combining low-frequency siderostat encoder information (star trackers) with siderostat acceleration measurements.

Finally, the two stellar beams are combined at a beam splitter and directed to the two fringe detectors (FD). One FD disperses the fringe across a 64 pixel CCD line on the WTD, with 5 nm spectral bandwidth per pixel. This provides both broadband tracking information to the ODLs as well as high visibility, narrowband measurements (NVIS detector). The other uses a photon-counting avalanche photodiode (APD) detector, in conjunction with synchronous pathlength modulation, to provide broadband information for fringe tracking (BVIS detector).

The **support electronics** supply the commands, conditioning and power for *SITE*'s sensors and actuators. The trade options ranged from using radiation-hardened and vacuum-tolerant electronics mounted inside the instrument to keeping the electronics in the middeck or Spacehab. However, one MPESS-mounted ESM container was selected because the electronics are mounted near the instrument to reduce manifesting complexity and the container enables forced convective cooling allowing the team to draw upon MODE, MACE, and Palomar digital and analog design experience. Figure B.4-4 shows the various functions of the ESM. This design maximizes use of relatively inexpensive off-the-shelf components to service the 22 real-time actuators; 28 real-time analog and 7 digital data signals; one fiber optic laser feed; 14 mechanisms; 10 heaters; and various other housekeeping signals. In addition to the services in Table B.4-1, 22 aft flight deck switches are provided for power activation, system reset, and redundant shutter and latch control.

Software allows the instrument to function as an integrated experiment. Options included upgrading MACE DSP code, acquiring select modules from Palomar, or using the experience garnered from Palomar to write *SITE*-specific code. Moreover, it was important to decide whether operation of the instrument would entail substantial crew involvement or be controlled largely from the ground. In the end, the large repository of extant Palomar software dictated borrowing to the maximum extent possible while creating *SITE*-specific code whenever necessary. Also, the relative complexity of the experiment makes it easier to control orbital operations from the ground since HitchHiker provides high-data rate communication to GSFC. Lastly, a premium was placed on using MACE experience in designing the software interfaces with the carrier.

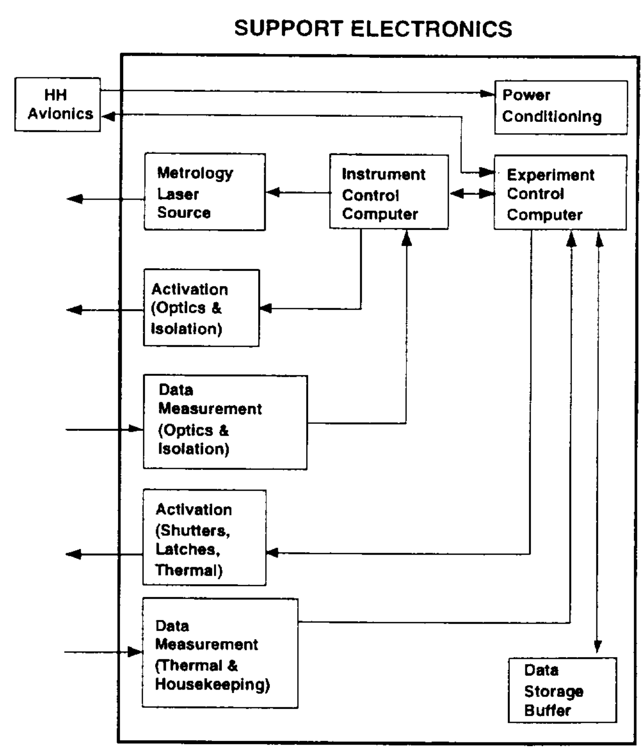

Figure B.4-4: ESM functional layout

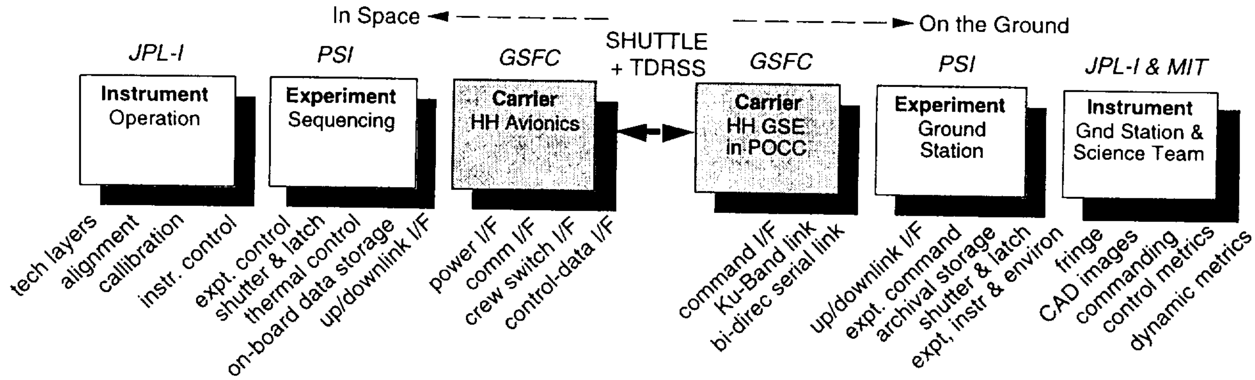

Figure B.4-5: *SITE* software subsystem connectivity

A three-layer computer architecture was devised (Figure B.4-5). The Palomar-derived *instrument* control system provides real-time operation of the structural and optics subsystems in orbit and serves as the ground team interface at GSFC. This VME hardware consists of off-the-shelf and custom circuit cards provided by JPL-I. PSI will provide an *experiment* interface which will route housekeeping data from the ESM, through the carrier, to GSFC. This includes access to the HitchHiker (HH) Avionics, instrument health monitoring, latch and shutter commanding, experiment execution, data storage and error checking. Data will be temporarily stored on nonvolatile flash EPROM in the ESM and periodically downlinked to GSFC. The third layer is the carrier-provided HH avionics and ground support equipment (GSE). In this nested architecture, JPL-I interfaces with PSI, while PSI interfaces with the carrier.

B.4.3 Modeling and Performance Estimation

This section summarizes the detailed analysis conducted to ensure that Req. 1.0 can be met. The design margin in Req. 1.1 was deemed appropriate to allow realistic costing of the hardware. This requirement places design margins on optical, static and dynamic misalignment.

Of the allowable 0.25 degradation in visibility, 0.15 was attributed to optical imperfections such as differential polarization effects, asymmetric polarization, beam overlap errors, as well as static optical aberrations. Many of these are minimized by good design, although the static aberrations of even good quality optics will introduce a fixed visibility reduction. The optical specifications in Req. 1.1.1 result in V=0.13 for a bandpass of 80 nm. The dispersed fringe detector provides 5 nm bandpass for each of 64 spectral lines. Therefore, the optical design meets Req. 1.1.1. Thermal gradients and gravity offload result in 70 arcsec misalignment each. Therefore, articulating alignment mirrors are used in the opto-mechanisms subsystem to meet Req. 1.1.2. Residual alignment errors will cause a 0.03 reduction in visibility.

The dynamic disturbances include wavefront tilt and differential pathlength arising from payload bay accelerations. To model these accelerations, SAMS data was used in conjunction with VRCS information acquired from the JSC Pointing Office for ±1° and ±0.1° deadband inertial holds. The resulting acceleration autospectra, shown in Figure B.4-6, is dominated by the Ku antenna pointing system at 17 Hz and its 3^{rd} and 5^{th} harmonics. A coupled isolation-structure-control-optics model was developed and subjected to these disturbances. A finite element model (FEM) of the *SITE* instrument (Figure B.4-7) was coupled to a 2200 degree-of-freedom MPESS model and ray tracing was used to compute wavefront tilt (WFT) and differential pathlength (DPL) and their effects on visibility.

Figure B.4-8 illustrates how control is used to reduce the impact of wavefront tilts and differential pathlength on fringe visibility. The accelerations (d) in the payload bay enter the MPESS/*SITE* system through the attachment trunions and are attenuated by the isolation system before reaching the structure. The remaining accelerations result in WFT and DPL, as shown by the solid lines. Feedback (dashed) and feedforward (dotted) control are used to further attenuate these accelerations before they impact the overall optical performance metric (visibility).

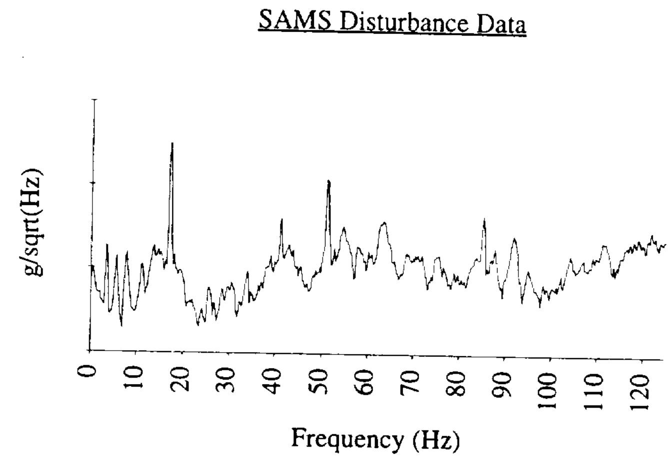

Figure B.4-6: Shuttle disturbance environment from SAMS data.

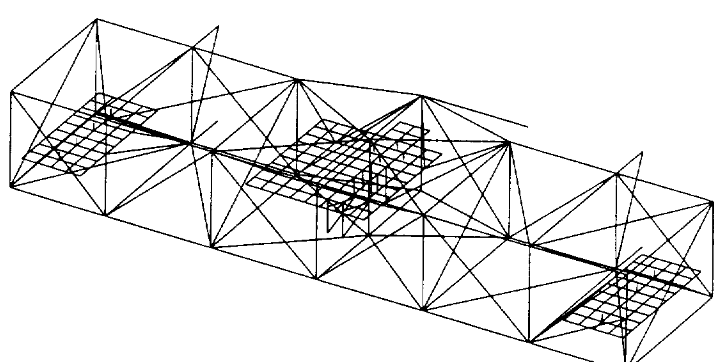

Figure B.4-7: FEM isometric grid.

Wavefront tilt is comprised of the tilts at the port and starboard apertures of the *SITE* instrument (WT_{port} and WT_{star}). Tilt in each individual path is controlled using a siderostat (SID) and fast steering mirror (FSM). First, the wavefront tilt detector (WTD) estimates the two absolute tilt errors. Second, the commanded correction angle is fed to the respective port and starboard FSM and SID combinations (PFaS and SFaS, respectively). These angular adjustments minimize absolute tilt error and, in turn, differential wavefront tilt.

Differential pathlength, shown at the bottom, is composed of internal (DPL_{int}) and external (DPL_{ext}) DPL errors. First, the internal laser metrology is used to minimize DPL_{int}. Second, the total DPL is estimated by the fringe detector (FD) and fed to the ODL to minimize total DPL. Note that the bandwidth with which WTD and FD can be fed back is proportional to the brightness of the stellar target and the amount of science light diverted to these detectors. At low frequencies, the wavefront tilt control system acts as a star tracker. By measuring the angle between the baseline and the line-of-sight, DPL_{ext} can be estimated. At higher frequencies (which encompass the flexible modes in the system), accelerometers placed at each siderostat are used to estimate DPL_{ext}. These low and high frequency estimates are combined and fed forward to slew the ODL. This corresponds to disturbance feedforward.

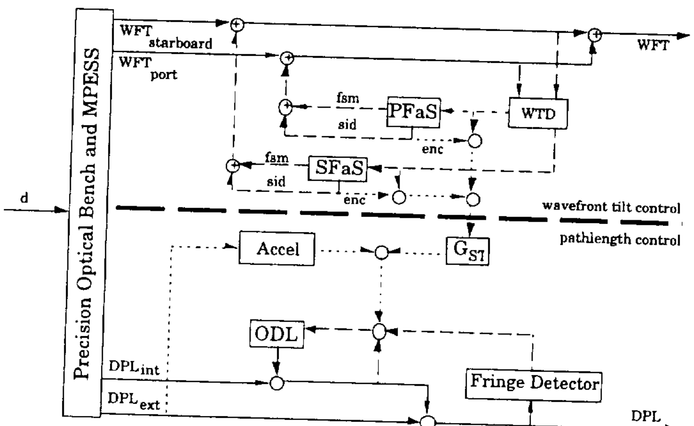

Figure B.4-8: The *SITE* control block diagram

Figure B.4-9 summarizes the visibility reduction caused by optical, static and dynamic misalignments. These reductions are shown for three stellar magnitudes and for vibration suppression (damping) and isolation present. In the 'damping' column, the 0.3% damped truss is actively augmented to achieve 3% structural damping. For an m_V=5 star, vibration suppression and isolation are enhancing technologies since V=0.86 when neither are used. For an m_V=8 star, both technologies are needed to enable visibility measurements in excess of 0.75 and enhance performance to as high as V=0.85. Both vibration suppression and isolation are enabling technologies for an m_V=10 star, causing visibility to increase from V=0.08 to 0.67 through their use. However, vibration suppression and isolation might have to be used together with other technology layers to achieve V=0.7.

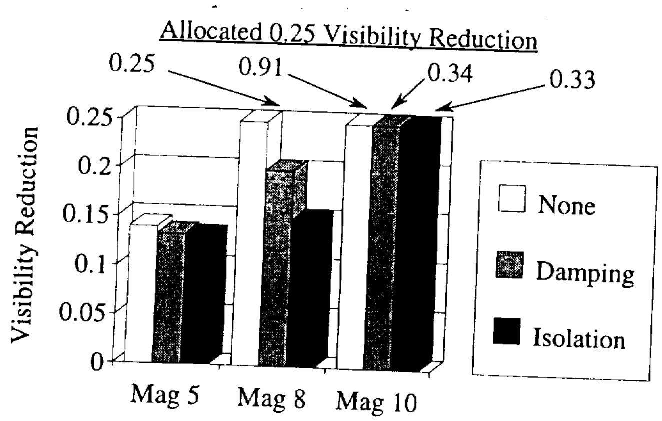

Figure B.4-9: Estimated visibility reduction using several technology layers.

This integrated model used in this analysis will evolve throughout the program. MIT's finite element model, which captures dynamics, thermal, control, and gravity effects, will be combined with JPL's IMOS optical model. MIT's prototype truss (acquired in Phase B) will be used to update the static and dynamic portions. The model will track the allocated subsystem error budgets throughout the design phases and will continually be updated as hardware integration progresses.

B.4.4 Operations

The *SITE* instrument has three primary operating modes: calibration, autocollimation (fringe capture with internal stimulus), and operation. In the calibration mode, the Shuttle aligns its IMU using a target star. Simultaneously, the siderostats acquire the same star to align the instrument line-of-sight (LOS). The error between the IMU and *SITE* LOS will be given to JSC pointing operations as a correction factor when inertially pointing the Shuttle. JSC recommends this coalignment procedure, to account for thermal and MPESS mount misalignments, because it helps avoid pointing iterations.

Autocollimation occurs before the shutters are opened and consists of rotating the siderostats 45° to retroreflect light from an internal stimulus, located on the beam combining bench, which has propagated through the science light path. This procedure is used to determine the health of the components and align the optics. It also provides a functional check after each pre-flight environmental test. Once internal integrity is confirmed, the siderostats are rotated back, the shutters are opened, and operations are initiated.

The operational mode consists of pointing, acquisition, and tracking of external stellar targets. First, the component technologies are activated and the internal laser metrology is used to slew the ODLs and quiet internal differential pathlength (1 min). Second, the Shuttle is inertially pointed at the selected star to ±1° accuracy and the SID/CAD pairs capture the star along their respective LOSs (2 min). Third, beam steering control shifts to the SID/FSM/WTD combination to zero wavefront tilt (1 min). Fourth, the external metrology is fed forward to the ODLs to coarsely zero the DPL after which the ODLs begin a scanning operation to hunt for the fringe (1 min). Once found, the fringe-tracking control loop is closed and measurements of fringe visibility are acquired in the broad and narrowband channels (5 min). In total, each stellar observation made under the operational mode requires about 10 minutes.

B.4.5 Risk Management

The identified risks lie in four categories: performance; design; maturity; and programmatics. There is a performance risk that Requirement 1.0 cannot be met. In this event, the *SITE* instrument allows observations of m_V = 5.6 and brighter stars. Also, *SITE* is designed to allow operation during free drift modes of the orbiter. The *SITE* operations team can also request that operations be conducted so as not to conflict with times of high crew activity, such as exercise periods.

To reduce the risk of major instrument failure prior to launch, *SITE* will be extensively system tested and the hardware will simulate fringe capture and tracking of an m_V = 8 star. In the event of a failure, *SITE* is equipped with active means to adjust instrument alignment, can operate in a star tracking mode with either optics arm separately, has means for diagnosing failure, and can still achieve major subsystem objectives.

The design risks specifically associated with flight hardware development are controlled through a series of steps spanning the entire program. First, the SERC-funded optics breadboard, along with select prototype hardware, will be used to recategorize all risk = 4 components prior to CDR. This also allows early identification of design flaws as well as long-lead procurement items, thus holding delays to a minimum. Second, the hardware design will be placed under configuration control immediately following CDR. Subsequent changes to the design will be subject to guidelines in the *SITE* configuration change policy. Third, after fabrication is completed, the hardware will undergo acceptance tests under the direction of MIT SERC, as well as all certification tests required to comply with SSP interface requirements and safety policy. Fourth, Palomar-derived software will be maintained in a configuration-controlled state through all phases of development and operation. In combination with the extensive spaceflight experience of the project team, the procedures described in this section will serve to minimize design risks and ensure successful achievement of *SITE* program objectives.

Maturity risk must be mitigated to the level appropriate for a NASA Class D flight experiment. To this end, *SITE* draws upon over 100 person years of research, development, and operation experience in interferometry by the team members. JPL-I's work on the MARK III interferometer on Mt. Wilson, ASEPS-0 program to build the Palomar and Keck Interferometers, and the design studies for OSI, SONATA, and a lunar surface interferometer are complemented by JPL-C's and MIT SERC's technology testbeds.

Programmatic risks are those which impact cost and schedule and include the detail of the design used for costing and scheduling, the maturity of the WBS, the availability of flight qualified hardware versus custom design, and ease of carrier integration and manifesting. The design involved a detailed analysis of system performance using Shuttle pointing information from JSC, MPESS specifications from GSFC, SAMS data, and NASTRAN and IMOS modeling tools. This effort included a detailed equipment list with component connectivity layouts and risk categorization. Margins, appropriate for a conceptual design, have been levied. The sixth level WBS, summarized in Part C, assigns high level responsibilities and deliverables to the team members most experienced for the task. Launch/landing load alleviation in the isolator latches is viewed as the most cost-effective means for reducing survivability risk and maximizing the use of off-the-shelf components. Finally, ensured instrument containment, without violating the payload bay door closure envelope, is preferable over component-level, carrier-required analyses and software certification. The one programmatic risk which is not under the team's control is manifesting, for which a work around plan must be developed. Otherwise, the team has conducted two cost and schedule rounds, along with a JPL Red Team Review, to ensure that the budget is realistic and attainable.

PART C WORK BREAKDOWN STRUCTURE

Figure C-1 shows the Work Breakdown Structure (WBS) for the *SITE* program detailed through level 4. A fifth and sixth level were developed to assist in developing the Resources Plan. Notice that the tasks under WBS-3.0 correspond to the subsystems described in Section B.4. The schedule and task descriptions have a one-to-one correspondence to this WBS.

PART D SCHEDULE PLANNING

D.1 SCHEDULE PLANNING

Figures D-1 and D-2 show the Phase B and C/D schedules, respectively. In both, most management and system engineering tasks permeate the entire program and are therefore not listed. Instead, the top portion of each schedule shows key program milestones. Care has been taken to maintain a one-to-one association with the tasks listed in the WBS.

D.2 TASK DESCRIPTIONS

Management (1.0): Management tasks permeate the entire program. For example, planning, scheduling and tracking are continuously conducted for technical as well as financial activities. The PI organization (SERC) conducts weekly videocons with JPL and meetings with SERC team members and PSI. As shown in Task 1.1, these weekly interchanges are used to identify progress with respect to the implementation plan developed in Phase A and the schedule. When problems arise, it is SERC's responsibility to develop work-around plans. Problems which could have major impact on program resources, such as launch slip, will have plans developed in advance.

Financial planning and tracking of the program occurs in WBS Task 1.2 on a weekly basis. Actual and accrued expenses are tracked with respect to the budget and forecasts of funding authorization are updated and reported to the Program Monitor to avoid financial resource shortfalls at program critical times such as flight hardware procurement. Since both MIT SERC and JPL receive funding directly from In-Step, it is particularly important that contract modifications for both institutions are coordinated and communicated. Forecasts of both overruns and underruns in excess of $100,000 (approx. 1% of the program) will be immediately reported to the program monitor in Task 1.3.1. Similar financial and technical management activities are conducted at JPL and PSI (1.4).

Discrete event Phase B management activities include reviews, such as the Conceptual Design Review (CoDR) and Requirements Review (RR), and the formation of the Science Advisory Committee (SAC). The SAC will be partially comprised of the Stellar Interferometry in Space Working Group (SISWG) and allows the *SITE* team to maintain program traceability to the larger NASA programs in interferometry. Interaction with the Commercial Industrial Review Committee is conducted under this task. Technical and financial tracking and forecasting are continued in Phase C/D. Additional reviews include the Critical Design Review (CDR); the Flight Readiness Review; and Post Mission Experiment Review (PMER).

System Engineering (2.0): System Engineering includes tasks which permeate all aspects of the program. For example, Requirements (2.1) includes revision of the ERD developed in Phase A and its flow down to the requirements levied on the subsystem leaders in 2.1.2. Constraints such as power, volume, mass, downlink, pointing, etc. are quantified in 2.3.5. These tasks drive the design tasks in 3.0. The requirements are frozen at the Requirements Review in Phase B.

Design and Evaluation (2.2) involves engineering tasks which couple the subsystems; such as detailed modeling, control design and performance evaluation to continuously track the ability of the system to achieve the program objectives. Development occurred in Phase A, refinement is a Phase B task and maintenance occurs in Phase C/D when Configuration Control (2.3) takes over to ensure that delivered subsystems meet their resource allocation and interface requirements.

An important Phase B task is Technical Risk Management (2.4). A detailed equipment list was developed during Phase A with each critical component categorized. The criticality of component functionality and launch survivability to program success demands that category (4) components be recategorized through analysis and test prior to CDR. Finally, Program Reviews (2.5) encompasses preparation and support of all major design reviews.

Subsystem Design & Fabrication (3.0): This task comprises the design and procurement of all of the *SITE* subsystems. Notice that Software (3.6) and Ground Support Equipment (3.7) are high level tasks because of the software complexity and realtime flight operations conducted at GSFC.

SITE

1.0 MANAGEMENT

1.1 Planning, Schedule & Tracking
- 1.1.1 Organization and Meetings
- 1.1.2 Schedule Maintenance
- 1.1.3 Implementation Plan
- 1.1.4 Work-Around Plans
- 1.1.5 Monitoring & Tracking
- 1.1.6 WBS maintenance

1.2 Financial
- 1.2.1 Budget Update & Forecast
- 1.2.2 Subcontract Monitoring

1.3 Customer Interface
- 1.3.1 Program Monitor
- 1.3.2 Science Advisory Comm.
- 1.3.3 Comm. Indust Review Comm.

1.4 JPL & PSI Internal Mgmt
- 1.4.1 Planning & Schedule
- 1.4.2 Technical & Task Tracking

1.5 Quality
- 1.5.1 Quality Program Plan
- 1.5.2 Nonconformance Tracking

2.0 SYSTEM ENGINEERING

2.1 Requirements
- 2.1.1 Expt Req Document
- 2.1.2 Subsystem Req. Docs.

2.2 Design and Evaluation
- 2.2.1 System Architecture Defn
- 2.2.2 FEM & Loads Analyses
- 2.2.3 IMOS Model & Perf. Eval

2.3 Configuration Control
- 2.3.1 Design Documents
- 2.3.2 Define Subsystem Interfaces
- 2.3.3 Subsystem Accept. Criteria
- 2.3.4 System Acceptance Criteria
- 2.3.5 System Budgets/Allocations

2.4 Technical Risk Management
- 2.4.1 Equipment list update
- 2.4.2 Make/buy Categorization
- 2.4.3 Testing, Anal. & Vendor Eval

2.5 Program Reviews
- 2.5.1 Design Reviews
- 2.5.2 Requirements Review
- 2.5.3 Non-Advocate Review
- 2.5.4 Flight Readiness Review
- 2.5.5 Post-Mission Expt Review

3.0 SUBSYSTEM DESIGN & FAB.

3.1 Structure
- 3.1.1 MPESS Interface
- 3.1.2 Precision Truss
- 3.1.3 Vibration Suppression
- 3.1.4 Thermal Control
- 3.1.5 Containment & Shutters

3.2 Isolation
- 3.2.1 On-Orbit Isolation
- 3.2.2 Launch Latches

3.3 Opto-Mechanisms
- 3.3.1 Pointing Control Subsystem
- 3.3.2 ODL Mechanism & Servo
- 3.3.3 Alignment Mechnisms
- 3.3.4 Inertial Feedforward
- 3.3.5 Mounting Plates, Attach H/W

3.4 Optics and Metrology
- 3.4.1 Fixed Optics & Mounts
- 3.4.2 Beam Combining Subsystem
- 3.4.3 Internal Pathlength Metrology
- 3.4.4 Detectors & Camera Heads
- 3.4.5 Internal Stimulus

3.5 Support Electronics
- 3.5.1 Experiment Control Comp.
- 3.5.2 Instrument Control Comp.
- 3.5.3 Signal Conditioning Syst.
- 3.5.4 Signal Amplifier System
- 3.5.5 Containment
- 3.5.6 Power Distribution System
- 3.5.7 Data Handling & Storage Sys.
- 3.5.8 Metrology Laser Source

3.6 Software
- 3.6.1 Experiment Control
- 3.6.2 Instrument Control
- 3.6.3 Crew Interface
- 3.6.4 Experiment Ground Station
- 3.6.5 Instr. Grnd Station (Control)
- 3.6.6 Instr. Grnd Station (Anal.)

3.7 Ground Support Equipment
- 3.7.1 Shipping & Test
- 3.7.2 Ground Station
- 3.7.3 Pseudostar

4.0 INTEGRATION & VALIDATION

4.1 Instru Subsystem Integ
- 4.1.1 Pointing benches at JPL
- 4.1.2 Phasing interferometer at JPL
- 4.1.3 Structure & Isolation at MIT

4.2 Flight Model Integration
- 4.2.1 Integ Planning & Doc
- 4.2.2 Test Planning & Doc
- 4.2.3 Subsys Accept/Cert Testing
- 4.2.4 System Integration
- 4.2.5 Functional Testing/Charact
- 4.2.6 System Accept/Cert Testing

4.3 Carrier Integration
- 4.3.1 Form 1628 & CPR Submittal
- 4.3.2 Integ Reviews (CIR, FOR,...)
- 4.3.3 Safety Reviews (0, I, II, III)
- 4.3.4 Payload Integ Plan/Annexes
- 4.3.5 Interface Control Doc (ICD)
- 4.3.6 Crew Training
- 4.3.7 JSC & GSFC Interface
- 4.3.8 Material Lists
- 4.3.9 Packing & Stowage Plans

5.0 OPERATIONS

5.1 On-Orbit Procedures
- 5.1.1 Diagnostics & error id
- 5.1.2 Alignment
- 5.1.3 Protocal format
- 5.1.4 Carrier pointing procedures

5.2 GSFC JSC & KSC
- 5.2.1 FM Delivery & Recovery
- 5.2.2 Mission Science Support
- 5.2.3 Mission Control Support
- 5.2.4 On-Orbit Predictions Doc.

5.3 Post-Flight Data Analysis
- 5.3.1 Archiving
- 5.3.2 Perf Analysis wrt Objectives
- 5.3.3 Perf Analysis wrt Cust. Needs
- 5.3.4 Reporting & Dissemination

Figure C-1: *SITE* Work Breakdown Structure

respectively. Phase B involves the finalization of the conceptual design and conduct of the preliminary design. The primary responsibilities for these subsystems are shown in Figure D-3. However, this does not imply that there is no involvement by other team members. For example, JPL-I provides a significant portion of the flight software, even though PSI has ultimate responsibility for delivering the flight system software. In the Resources Plan, a budget for prototyping critical structural, isolation, and optical components has been allocated in Phase B.

Integration & Testing (4.0): Integration and Testing is comprised of subsystem integration and functional tests; carrier integration; and environmental testing of the flight hardware. Figure D-3 illustrates the hardware flow starting with subsystem fabrication, through subsystem integration at both JPL and MIT, and ending at final flight system integration at PSI. Most of these tasks occur in Phase C/D with the exception of the Form 1628 and Customer Payload Requirements (CPR) Submittal (4.3.1); and the Phase 0/I Safety Review (4.3.3). Form 1628 provides NASA HQ's authorization to initiate contact with the Shuttle integration organizations at JSC and GSFC (MPESS HitchHiker). It is imperative that this submittal occur at the beginning of Phase B since all carrier integration tasks start at this point and drive the duration of the program. The Customer Payload Requirements document is the governing document for all HitchHiker payloads listing requirements, design, integration, and safety subsystems. An initial version of this will be completed during Phase B and modified in subsequent phases as the design matures. The Phase 0/I Safety Review is the first step in carrier integration and identifies the safety critical systems as well as plans for resolution supplied to the carrier's safety office.

Operations (5.0): Operations are Phase C/D activities which define how the experiment will be operated on orbit (5.1) and from the ground through the *SITE* POCC at GSFC (5.2). Chronologically, on-orbit procedures development occurs concurrently with flight model integration (4.2). Task 5.2 corresponds to the conduct of the mission by the *SITE* operations and science teams at GSFC and JSC. Task 5.3 captures and disseminates the flight results to the user community. This involves development of the design guide illustrated in Figure B.2-1 which quantifies the measured visibility for a given stellar magnitude as a function of technology layering and disturbance environment. Technology layer performance will be reported in terms of both incremental impact and measured visibility as well as improvement in its respective technology metric (e.g., transmissivity for isolation). Equally important is the assessment of pre-flight model accuracy. Flight measurements will be compared with these models to develop a measure of model uncertainty which provides bounds for future mission modeling efforts. Dissemination occurs primarily through the Science Advisory Committee. MIT SERC will transfer the technology and experience gained by conducting a short course based upon *SITE*, developing a Mosaic page for rapid data dissemination, presenting at technical conferences, and publishing journal articles.

PART E MANAGEMENT PLAN

E.1 PROJECT ORGANIZATION AND MANAGEMENT APPROACH

The MIT Space Engineering Research Center (SERC) and the NASA Jet Propulsion Laboratory (JPL) have assembled a project team prepared to maximize the probability of experiment success, to minimize development risks, and ensure compliance with all the appropriate NASA Space Shuttle Program (SSP) safety, integration, and certification requirements. This team stands ready to successfully complete the *SITE* project on time, on budget, and with the highest possible scientific standards. SERC and JPL provide technical and scientific leadership to the team, while the MIT Center for Space Research (CSR) provides financial and administrative management. The primary subcontractor, Payload Systems Inc. (PSI), is a small business with an extensive background in manned spaceflight experiments. PSI will fabricate the hardware for *SITE* as proposed herein (with some major components being procured by JPL), and will be responsible for all experiment integration tasks. The MIT/PSI team is identical to that assembled to perform MODE-I, MACE, and MODE-Reflight, and, with the addition of JPL, will perform *SITE* with the same superior standards exhibited by those projects.

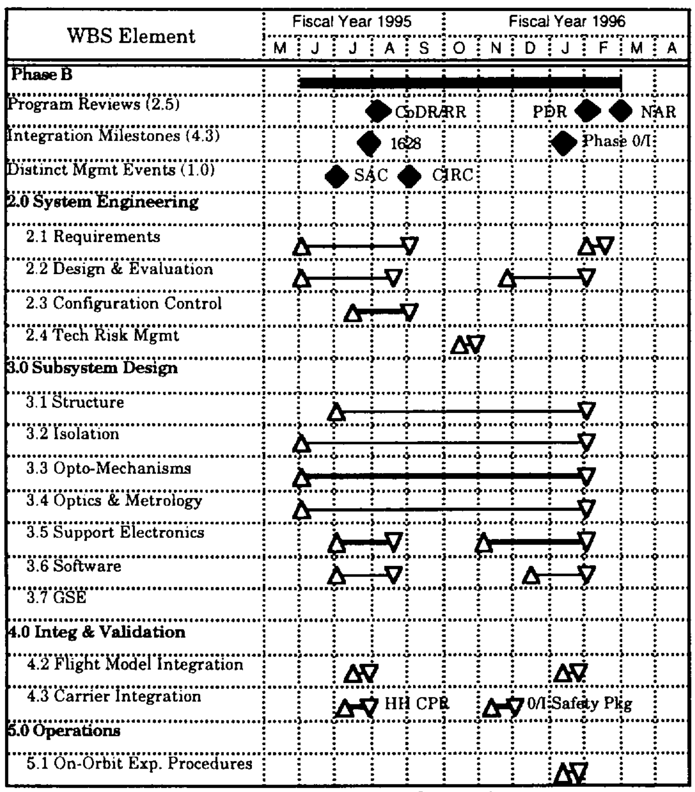

Figure D-1: Phase B Schedule

Responsibilities for the *SITE* project are divided into five major categories: *project management*; *systems engineering, mechanisms and isolation, optical benches and software;* and *flight systems and integration.* These latter four are further broken down as shown in Figure E.1-1 below. Project Management is divided into management and fiscal control. Quality, though performed at Payload Systems, reports directly to the *SITE* PI, thereby providing independent quality control oversight. Also shown on the figure are interfaces with NASA project management and integration staff, as well as the two *SITE* advisory committees.

Project Management includes fiscal management, sub-contractor oversight, administration, performance assurance, and configuration control. Activities include financial reporting, contract negotiation, and certification of acceptance procedures. This task is the primary responsibility of MIT SERC, with administrative support from the experienced team at MIT CSR, and is the direct responsibility of the Co-PI/Project Manager.

Systems Engineering encompasses all *SITE* research activities both in the laboratory and in space. These activities include ground studies, flight procedures development, science operations during the flight, and postflight data analysis and reporting. These activities will be both managed and performed within SERC under the direction of the PI and Co-PI. They are assisted by SERC support staff and faculty, as well as graduate and undergraduate students.

Mechanisms and Isolation encompasses the development of the isolation system, the optical mechanisms, and the IMOS modeling of the structure. Since much of this will be directly derived from the experience obtained from the MPI testbed, JPL will be responsible for these tasks. JPL will also assist in the integration of these systems onto the flight unit. These tasks are the responsibility of the Mechanisms and Isolation Task Manager, assisted by JPL engineering staff.

Optical Benches and Software encompasses the development and integration of the optics and metrology into a single functioning system, and the software to control it. This work is directly derived from the extensive ground work that has already been performed at JPL. JPL will also assist in the integration of these systems onto the flight unit. These tasks are the responsibility of the Optical Benches and Software Task Manager, assisted by JPL scientists and engineering staff.

Flight Systems and Integration include all activities necessary to transform the laboratory-based experiment into a fully space-qualified Space Shuttle payload. These include fabrication of the structure, electronics, and mounting systems, as well as experiment control software and porting of JPL-developed software to the flight computer, and integration of the JPL-fabricated optical benches and isolation systems. Also included are the integration tasks: schedule, negotiation, and reviews leading to the allocation of Shuttle resources (weight, volume, power, crew time, ground processing, and flight operations) as well as successful compliance with Shuttle safety and certification requirements. These activities are the responsibility of the Hardware Development Engineer and the Integration Engineer, assisted by other members of the PSI engineering and technical staff, and under the direction of the PSI Project Manager.

E.2 KEY PERSONNEL AND RESPONSIBILITIES

The Principal Investigator for *SITE* is Prof. Edward F. Crawley, Director of SERC. Dr. Crawley was the Principal Investigator for the MODE and MACE projects. He provides overall scientific direction for *SITE*, particularly in scientific requirement definition and test matrix definition. Dr. Crawley is a world-renowned authority on structural dynamics and control, with over 75 journal and conference publications in the field. He will serve as the primary point of contact between the NASA program management and the *SITE* team. Prof. Crawley will be devoting approximately 20%, and 30% of his time to *SITE* during Phase B, and C/D respectively.

The *SITE* Co-Principal Investigator/Project Manager is Dr. David W. Miller, Associate Director of SERC. He is assisted in his management functions by the *SITE* administrator, responsible for fiscal and sub-contractor management. Dr. Miller will also direct the Systems Engineering effort, as well as being the primary point of contact with the JPL Co-Investigators. He was a Project Scientist on MODE and Co-Investigator on MACE, and is a widely published expert on structural design and

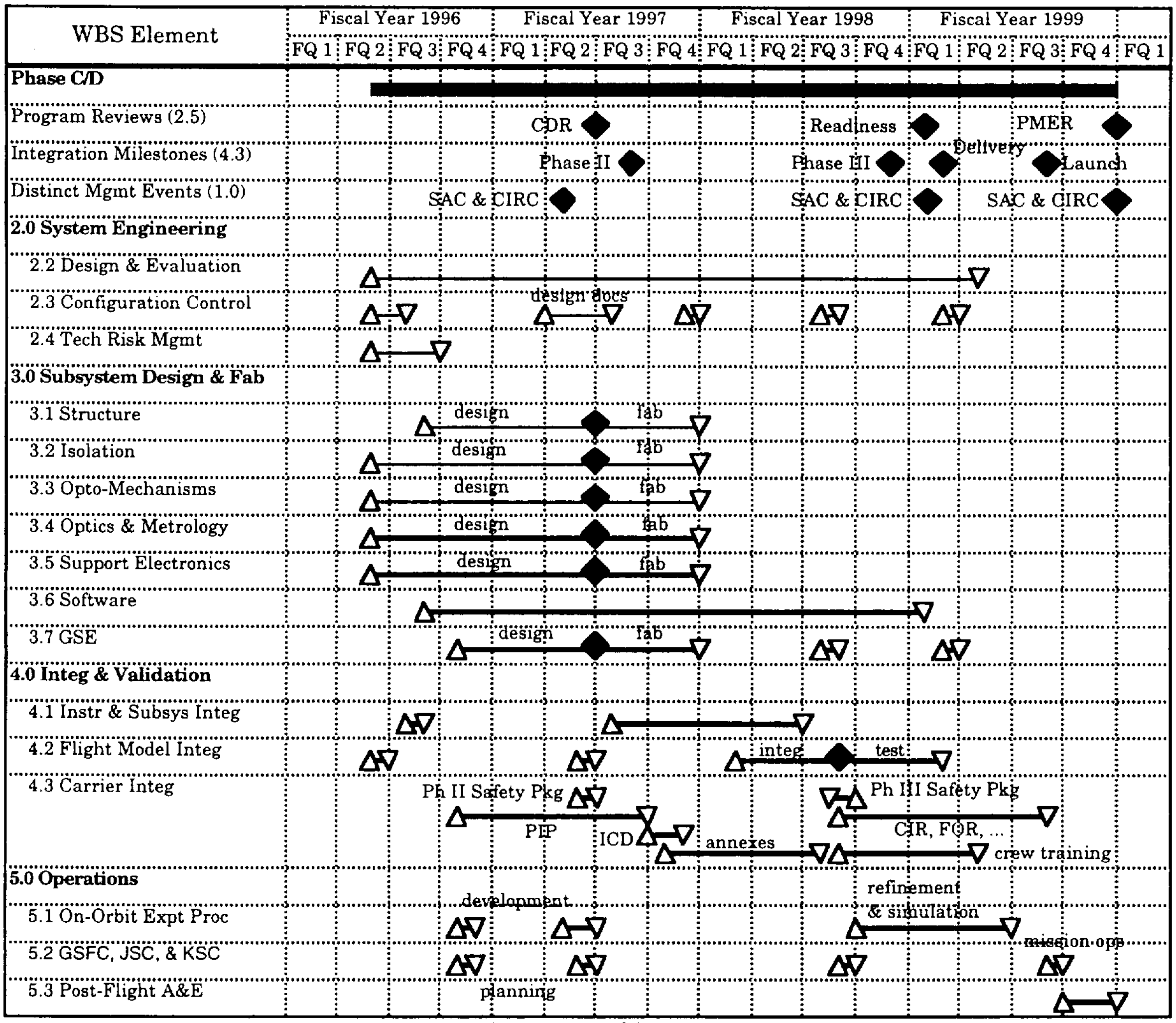

Figure D-2: Phase C/D schedule

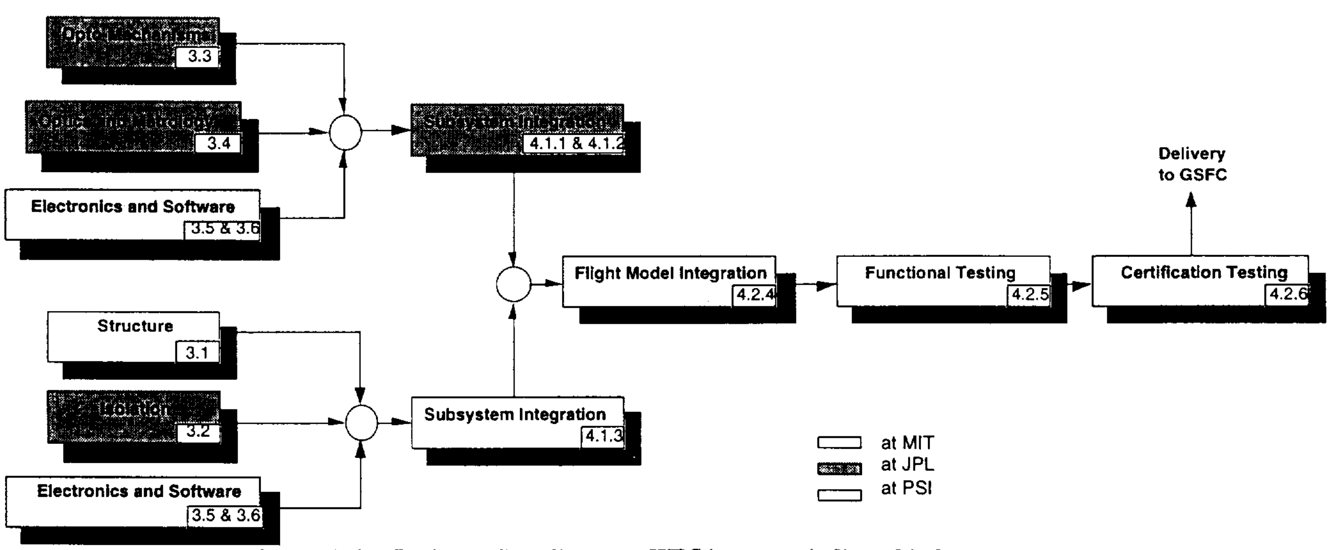

Figure D-3.: Hardware flow diagram. WBS items are indicated in lower corner.

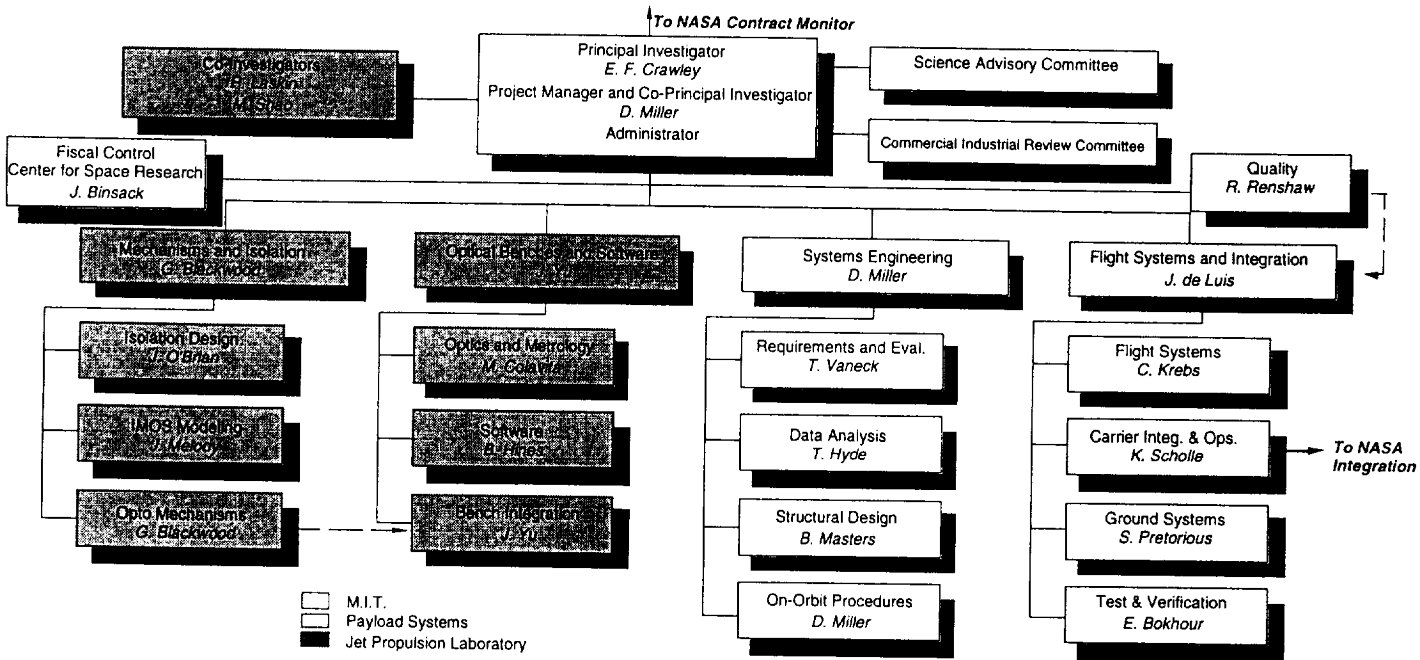

Figure E.1-1: Project organization and responsibilities for *SITE*.

control, with over 40 journal and conference publications. On MACE, Dr. Miller was responsible for the control selection and design, as well as for ground test operations of the various hardware elements. As Associate Director for SERC, he has lead the efforts to set up and operate several large ground testbeds, including the SERC interferometer testbed from which much of the expertise will be drawn from for *SITE*. Two full-time graduate students will also assist. Dr. Miller will be devoting approximately 80% of his time to *SITE*.

Co-Investigators at JPL are Dr. Mike Shao and Dr. Robert Laskin. Dr. Shao is a world recognized authority in optical interferometry and is the architect of the Mark I, II, and II ground based interferometer instruments. He has authored publications in scientific journals and serves as the group supervisor of the Spatial Interferometry Group at JPL. Dr. Laskin has served as the CSI task manager since 1991 and has authored over 30 journal publications in the field of dynamics and control of flexible structures. Dr. Shao and Dr. Laskin will insure the scientific and technological relevance to NASA's goals, and will spend 30% of their time on *SITE*.

Dr. Jeff Yu will be the task manager for the JPL Optical Benches and Software Task deliverables: optics and metrology, software, electronics, and overall instrument integration. Dr. Yu is an expert in electro-optical systems with several journal publications and has extensive experience at JPL in systems engineering and ground based interferometer integration. Dr. Yu will allocate 100% of time to *SITE* will be assisted by Dr. Mike Colavita and Mr. Brad Hines, each of which have extensive experience in the integration of interferometer instruments. Dr. Gary Blackwood will serve as the task manager for the JPL Mechanisms and Isolation Task deliverables: isolation, opto-mechanical devices, and IMOS integrated modeling. Dr. Blackwood is an expert in active vibration isolation and ground based CST testbed experimentation, with several publications in the field. Dr. Blackwood will spend 100% of his time on *SITE* and will be assisted by Mr. John O'Brien and Mr. Jim Melody from the CSI program. Key JPL personnel will also be present at PSI when the flight electronics is integrated with the flight optics from JPL as well as isolator and structure integration and flight systems integration.

As PSI Project Manager, Dr. Javier de Luis will direct the Flight Systems and Integration effort. As president of PSI, Dr. de Luis has been resonsible for the fabrication and integration of over a dozen spaceflight experiments over the last three years. In addition, he has been the PSI project manager for the MODE and MACE programs. Ms. Kimberly Scholle will be responsible for carrier integration and flight operations. She will additionally serve as the primary interface between the *SITE* payload and the SSP integration process. In the past three years, she has succesfully integrated over a half-dozen payloads on numerous carriers. Flight hardware development is the responsibility of Mr. Christopher Krebs, PE. Mr. Krebs served as senior mechanical engineer on the MODE and MACE projects. Before joining PSI, he designed and integrated several Shuttle payload bay experiments as well as sounding rocket interferometric payloads for the USAF. These three primary team members will be assisted by the PSI engineering staff, all of whom are experienced in designing and flying scientific payloads in space on several different carriers, including Shuttle, Spacelab, and the Russian *Mir* space station. PSI's participation will increase as *SITE* progresses. Mr. Krebs, and Ms. Scholle will devote approximately 100% and 75% of their time, respectively. Dr. de Luis will allocate 40% of his time to *SITE*. Additional PSI electrical, mechanical, and software engineers will provide significant additional manpower support, with over 5 full time equivalent engineers working on *SITE* during its design and manufacturing phases, in addition to the manpower already listed.

The project team brings to *SITE* broad-based and substantial experience in manned and unmanned spaceflight. The *SITE* team realizes the importance of a complete but streamlined management structure in the successful performance of flight experiments. Therefore, although the complete *SITE* team is not required at the onset of the project, the key members of the team are already in place and have been working together since before the start of Phase A. The members are prepared to continue their functions as the project transitions to Phase B. This serves to minimize transition time and development risk, while maximizing the expected scientific return.

E.3 CAPABILITIES, FLIGHT AND EXPERIENCE

The MIT Space Engineering Research Center (MIT) was formed in 1988 by NASA to serve as a university center of excellence for research into Controlled Structures Technology (CST), in recognition of its extensive laboratory experience and the leading role MIT has played in developing CST. SERC designed the highly successful MODE experiment, which flew on STS-48 in September, 1991, and again on STS-62 in March, 1994. It is now completing development of the MACE experiment, scheduled for launch on STS-67 in March, 1995. The MIT Space Systems Laboratory, from which SERC was created, has been involved in numerous flight experiments, most prominently the EASE experiment, which flew in the Shuttle payload bay in 1985.

The MIT Center for Space Research (MIT CSR) is an interdisciplinary organization within the MIT School of Science which draws faculty and research staff from a variety of MIT academic departments and disciplines to conduct experimental and theoretical space-based research. Major CSR accomplishments include the entire scientific payload for the X-ray satellite SAS-3, the Voyager Plasma Science Experiment, and flight experiments on SL-1, D-1 and SLS 1 & 2. Current activities include several AXAF spectrometry instruments and development and launch of its own satellite for the High Energy Transient Experiment.

Payload Systems Inc. (PSI) is a small business based in Massachusetts. Founded in 1984 to provide science and engineering services for spaceflight experiments, PSI has an outstanding history of supporting US and foreign investigators in transitioning from ground-based to space-based research. They are a leader in providing low-cost, high quality experiments to In-Step and other NASA flight projects. PSI was selected as the primary subcontractor because of their excellent performance on MODE, as well as related experience on other manned spaceflight experiments, including STS-9 and Atlas-1 (for which PSI provided a Payload Specialist), the STS-51D Ocular Counter-rolling Experiment, the STS-61A (D-1) Vestibular Schlitten Experiment, the IML-1 Mental Workload and Vestibular Investigations Experiments, and MACE.

The JPL Spatial Interferometry Group (JPL-I), which moved to JPL in 1989, has built the Mark III Interferometer on Mt. Wilson which, since 1986, has been in use by NRL, USNO, and JPL and is responsible for more scientific results than any other long baseline optical/IR interferometer. Current activities include the construction of the technology testbed for the Keck interferometer and a mission/systems study for a space interferometer (OSI) as well as ultra-precise (picometer level) laser metrology, stabilized ($<10^{-10}$) solid state lasers, development and use of optical diffraction propagation codes (e.g., to measure the spherical aberration of the HST), and conduct of astrophysics research with long baseline interferometers.

The JPL Control Structure/Interaction Program (JPL-C) was formed in 1988 and has, at a funding level of approximately $3M/year, been developing technology for future NASA missions requiring micron and sub-micron regime dynamic stability. The CSI team has extensive experience in the construction and operation of large precision structure ground testbeds. It has also developed component hardware, such as isolation systems active members and delay line optics, and modeling/design software for demonstration on these testbeds. Actuator hardware derived from the CSI active member has been flight qualified and is currently flying as part of the WF/PC-2 instrument on the Hubble Space Telescope. In another flight project application, the CSI developed Controlled Optics Modeling Package software was utilized in deriving the faulty HST's mirror prescription so that corrective optics could be incorporated.

E.4 INSTITUTIONAL SUPPORT

E.4.1 Organizational Commitment

The *SITE* project is of vital importance to MIT and SERC as a logical continuation of the research effort begun by previous SERC spaceflight experiments (MODE, MACE, MODE-Reflight) and as a key element in the ongoing CST development effort. Furthermore, *SITE* will provide an educational focus as well as unparalleled motivation and research experience for undergraduate and graduate engineering students completing their studies at SERC. Over the last several years, MIT SERC has focused significant funds and resources on the development of a ground-based interferometric testbed. Results from this effort support directly the current proposal The importance of *SITE* is evidenced by the participation of the Director and Associate Director of SERC as Co-PIs. Their participation assures that *SITE* will have high visibility within the Center and will be able to draw upon facility resources as necessary. Financially, Prof. Crawley's contribution as PI during the academic year is made at no direct cost to *SITE*. Additionally, MIT SERC will provide laboratory test equipment, low frequency suspension systems, and over 3000 square feet of laboratory space to *SITE*.

At Payload Systems, Dr. de Luis will act as the PSI *SITE* Project Manager. As president of PSI, his participation on the *SITE* team will provide the highest level of corporate support and commitment to this project.

JPL regards space optical interferometry as one of its long term areas for future mission development. The Laboratory brought Dr. Shao's interferometry group to JPL in 1989 from SAO, and has committed significant institutional resources towards the development of ground based interferometry and studies of space based interferometry. JPL commits Dr. Shao, the Laboratory's foremost interferometry expert, and Dr. Laskin, CSI task manager, as co-investigators of *SITE*. Perhaps most importantly, those JPL personnel who developed and integrated the Palomar interferometer and MPI testbed will be made available for *SITE*. The CSI group has committed 1.5 work-years of in-kind labor to the integrated modeling activity within MIT's system engineering task. In addition, the JPL CSI program is supporting four graduate students at MIT over the duration of the *SITE* program.

JPL as an institution is committed to the development of small Class D experiments on schedule and at low cost. The JPL Cryo-System In-Step Experiment aboard STS-63 in February 1995 was 100% successful in meeting its objectives and schedule, and was within 14% of original cost estimate. JPL regards In-Step as an important element in the recent laboratory focus on the smaller, less expensive science missions that will comprise the New Millenium program for which JPL has been designated lead NASA center.

E.4.2 Facilities and Equipment

MIT SERC is a fully functional, state-of-the-art dynamic testing and control laboratory. It has available several real-time control computers (AC 100, VME-based system), structural ID facilities (Tektronix), and computing facilities (Sun, Cray). The MIT ASTROVAC facility is also available for vacuum testing. MIT has developed, under SERC funding, a fully functional ground-based interferometer test-bed on which much of the technology to be used in *SITE* has been developed. In particular, optical equipment and laser metrology systems will be made available to the *SITE* project. MIT SERC also has developed several software tools and codes that will be useful to *SITE*, including control-design and structural ID software packages that have been used for MODE and MACE. Finally, the active suspension system developed for MACE will also be available for *SITE* testing.

JPL provides state of the art optics test and integration facilities, including clean optics space, in the new Observational Instruments Laboratory. The Dynamics Laboratory and MPI Testbed facility offer extensive dynamic test equipment for component characterization and control implementation, including a VME real time computer. JPL also provides extensive environmental test chambers: acoustic, vibration, static, and thermal/vacuum. The Molecular Contamination Instrument Facility is available for outgassing characterization.

Payload Systems has a 10,000 class clean-room facility dedicated to assembly and testing of spaceflight hardware, which is particularly important for the optics. Directly adjacent to the spaceflight hardware assembly room is an electronics and non-flight hardware assembly and checkout laboratory. PSI also has two Anvil CAD facilities dedicated to spaceflight hardware design tasks. Locked, limited access archive facilities are available for controlled drawings and documents. All items procured for flight hardware fabrication are tracked on a software platform developed specifically for that purpose by PSI. Other facilities of interest include a configuration-controlled software development suite on dedicated PCs. For *SITE*, Payload Systems will procure a portable, Class 1000 clean room for assembly and handling of all optical equipment.

For budgeting purposes, vibration and thermal testing has been assumed to be conducted at the Langley Research Center facilities, charged at the standard non-NASA rates. EMI and offgas testing will be conducted at JSC facilities, as provided in the standard Payload Integration Plan. Availability of these facilities is negotiated during the standard integration process.

E.5 MANAGEMENT FUNCTIONS

This section outlines the policies and procedures that will be used to ensure successful project completion without placing unreasonable burdens on the project budget and resources.

E.5.1 Science Development Management

MIT will ensure successful achievement of the *SITE* technical goals by verifying that all engineering science requirements are met. This will be accomplished in three stages. First, a formal Experiment Requirements Document (ERD) has been written and baselined; all subsequent technical requirements and designs will be derived from it. The ERD and derived documents will be under formal configuration control. Second, the PSI team will participate during the fabrication of all *SITE* prototype hardware, providing design guidance with regards to flight hardware development and certification issues. This will minimize changes between ground and flight components, and will familiarize the team with the engineering requirements and objectives. Third, the PSI *SITE* Project Manager, Dr. Javier de Luis, will participate in all engineering discussions and meetings at MIT, serving as a conduit between the engineering science and the flight hardware development.

E.5.2 Development Risk Management

In addition to risk minimization methods applied in project management and experiment integration tasks, the risks specifically associated with flight hardware development are controlled through a series of steps spanning the entire project schedule. First, the SERC-funded optics breadboard will be used to identify potential problems before prototype or flight hardware design has commenced. Second, fabrication of certain key prototype hardware will be concluded prior to the Hardware Critical Design Review, allowing early identification of any design flaws and potential solutions as well as long-lead procurement items necessary for flight hardware fabrication. Thus redesign and procurement delays will be held to a minimum. Third, some prototype testing will be completed prior to the Hardware Critical Design Review, so that performance and environmental data will be available before the detailed design of the flight hardware is finalized. Fourth, the hardware design will be placed under configuration control immediately following CDR. Subsequent changes to the design will be subject to guidelines in the *SITE* document change policy. Fifth, after fabrication is completed, the hardware will undergo acceptance tests under the direction of MIT SERC, as well as all certification tests required to comply with SSP interface requirements and safety policy. In combination with the extensive spaceflight experience of the project team, the procedures described in this section will serve to minimize development risks and ensure successful achievement of *SITE* project objectives.

E.5.3 Configuration Management

Configuration management is an integral part of producing high quality products and services which fulfill customer requirements. It comprises three activities: identification, control, and status tracking. PSI has developed a *SITE* Configuration Management Plan describing the implementation of: Requirements; Design; Acceptance Criteria Specification Documents; Development, Certification, and Integration Plan; Configuration Identification Record (containing a definitive listing of all controlled items and their level of control); Document/Drawing/ Schematic, Hardware, Software, and Change Control (all tracked in respective logs); and Configuration Status Tracking (central log containing records of all change requests and their dispositions). These are the same tools successfully employed in all of PSI's spaceflight projects, including MODE and MACE, and they serve to minimize nonconformance incidents.

E.5.4 Quality

PSI will deliver all *SITE* hardware, software, and services in accordance with *SITE* project quality assurance/control procedures that are described in the *SITE* Quality Program Plan, and summarized here: The project Quality Engineer will ensure that quality concerns (including safety, reliability, maintainability, testability, producibility, supportability, and human engineering) are addressed in every aspect of the project, including project management, hardware design, procurement and fabrication, subsystem and integrated system testing, packing and shipping, and final flight readiness preparation. The Plan is compatible with a Class-D modified payload. It emphasizes prevention of nonconformances through total adherence to documented project requirements and will provide a comprehensive approach to detecting, documenting, and resolving nonconformances, with emphasis on preventing their recurrence. In support of the Plan, PSI will implement Inventory, Procurement, Fabrication, Non-Conformance, and Test and Evaluation Controls to ensure that all articles and materials procured and produced meet *SITE* project requirements.

The Quality Engineer will review and approve Quality plans from all major subcontractors delivering hardware and software components to PSI to ensure compatibility with the *SITE* Quality Program Plan. Since PSI is the integrator of the flight systems, JPL-delivered hardware and software will also be required to meet the quality standards as specified in the *SITE* Quality Program Plan.

E.5.5 Integration Documentation and Control

During on-orbit operations, the *SITE* test article will be located in the payload bay. We have kept the *SITE* requirements within the capabilities provided by the standard HitchHiker interface. We therefore expect most of our integration documentation to be governed by the Customer Payload Requirements document. By producing meticulous GSFC integration documentation, we are prepared to support any additional documentation requirements that may arise with minimal effort. Our approach will be to initiate productive interaction with all appropriate GSFC and JSC integration personnel early in Phase B; the excellent working relationship between PSI and JSC will contribute to the speed and accuracy of this process. All *SITE* reviews, launch and mission operations will be supported by appropriate team members at the necessary sites.

In addition to integration documentation and meetings, the *SITE* team will support the Phase Safety Process. The same philosophy applied to integration tasks will be applied to safety: the *SITE* Integration Engineer will establish contact with the appropriate safety personnel immediately following 1628 approval. The *SITE* team will support Phases 0/I through III Safety Reviews and will prepare exhaustive Safety Data Packages at each phase to minimize the potential for late payload redesign. This is the same method applied to MODE-I, MODE Reflight, and MACE. In all the safety reviews conducted for these projects, not a single action item was assigned to the payload organization. In fact, the Payload Safety Review Panel deemed the MODE Phase II Safety Data Package so complete as to make a Phase II meeting superfluous, and subsequently canceled the review. Of course, *SITE* presents a completely different set of safety concerns than those faced by MODE or MACE. In particular, placement of the interferometer and avionics in the payload bay will necessarily require careful attention to thermal, EMI, and fracture control. However, from the onset, *SITE* was designed with these issues in mind, hence the completely enclosed optical platform and avionics containers. Our preliminary safety analysis, as well as informal conversations with NASA JSC and GSFC personnel, have not identified any insurmountable safety critical issues.

E.5.6 Reporting, Meetings, and Reviews

The success of *SITE* will depend on excellent communication both within the team and with external organizations. To ensure seamless communication within the team, informal communication lines will be supplemented by a rigorous reporting structure. Weekly Project Team Meetings will be held at MIT will provide the team members with a regular opportunity to discuss task progress and will help to ensure early detection and resolution of schedule and technical problems. Video conferencing will be used to maximize information exchange with JPL and reduce travel costs. Monthly Telecons with the NASA Program Monitor will be conducted, and will provide the Program Monitor with regular technical and financial status updates. The Program Monitor will also be invited to participate in all other team meetings, at his/her discretion. Monthly Technical and Financial Reports and Quarterly Financial Reports (533 M and 533 Q) will be prepared by the Co-PIs based on status reports from PSI and submitted to the NASA Program Monitor. Finally, Scheduled Project Reviews will include the Requirements Review, Conceptual Design Review, Preliminary Design Review, Critical Design Review, Acceptance Review, and Post Mission Experiment Review as well as Interface Control Document/Payload Integration Plan Meeting and Phase Safety Reviews. Supporting materials will be provided to the NASA Program Monitor in advance of each review.

E.5.7 Sub-Contractor Management

The PSI *SITE* Project Manager will report to the Co-PIs on technical matters at the weekly project team meeting. Financial control of the subcontracts will be handled by the CSR. PSI will submit monthly billing statements and updated cost projections, which the Co-PIs will include in the financial reports submitted to NASA. This is the same organizational structure used successfully for the MODE and MACE projects.

E.5.8 Fiscal Control and Procurement

The Center for Space Research will be responsible for fiscal control for *SITE*. CSR has a long history of flight hardware development for NASA, and has at its disposal the necessary tools required for sound fiscal control. CSR will prepare and submit Monthly and Quarterly Financial Reports (533M and Q) to NASA. CSR will require PSI and JPL to submit similar reports which will also be forwarded to NASA for review. Information from these reports will be used to anticipate cost profiles and funding requirements. PSI and JPL will be responsible for the purchase of flight hardware components. Their extensive flight hardware experience has resulted in a large network of reliable, experienced suppliers who can deliver on-time and at reasonable cost. For all purchases over $1,000, PSI and JPL will solicit competing bids from multiple suppliers.

E.5.9 Schedule, Budget and Tasks

The project schedule shown in Figure D-1 and D-2 is extremely ambitious for the science, technology development, and integration complexity *SITE* will entail. In recognition of this fact, MIT, JPL, and PSI will strictly monitor *SITE* schedules, budgets, and task progress, to identify and resolve potential scientific or technical problems at an early stage and with minimum impact to the project. The Co-PI/Project Manager, the PSI Project Manager, and the JPL Task Managers will update the Implementation Plan that will serve as the source document for all management actions for the *SITE* project. The plan outlines the task, schedule, and Resources Plans for Phases B and C/D, along with corresponding controls. The Co-PI/Project Manager will work with the Project Administrator to track the status of all contract-related tasks through automatically generated weekly and monthly accounting reports. PSI and JPL will supply sufficient status information to enable the Co-PI/Project Manager to monitor the weekly progress of all flight systems and integration tasks.

Attachment B: The costs shown in the table below represent all project costs (in thousands) broken out by program phase (subdivided by Fiscal Year) and WBS elements. MIT and PSI costs have been combined since programmatically PSI is a subcontractor to MIT. JPL costs are shown separately. Only those tasks in which a SITE partner participates are shown in their respective table. The last line is a summary of the entire program.

MIT AND PSI	B (FY95)	B (FY96)	Phase B TOTAL	C/D (FY96)	C/D (FY97)	C/D (FY98)	C/D (FY99)	Phase C/D TOTAL	TOTAL (all phases)
MIT and PSI									
1 Management	**60.0**	**64.9**	**124.9**	**94.1**	**151.0**	**165.0**	**105.9**	**516.0**	**640.9**
1.1 Project Planning & Schedule	14.0	17.6	31.6	43.8	65.1	58.3	28.3	195.5	227.2
1.2 Financial	18.6	15.3	33.8	10.6	19.0	20.2	17.4	67.2	101.0
1.3 Customer Interface	1.7	2.2	3.9	3.8	3.9	11.3	7.6	26.6	30.5
1.4 JPL & Subcontractor Management	19.2	24.2	43.4	34.0	58.1	58.1	43.7	194.0	237.4
1.5 Quality	6.5	5.6	12.1	1.9	4.9	17.1	8.9	32.7	44.8
2 System Engineering	**151.9**	**115.2**	**267.1**	**209.2**	**291.8**	**126.6**	**72.5**	**700.1**	**967.2**
2.1 Requirements	37.9	4.0	42.0	-	-	-	-	-	42.0
2.2 Design & Evaluation	43.7	43.4	87.1	96.3	139.4	97.9	21.2	354.8	441.9
2.3 Configuration Control	13.6	-	13.6	59.2	67.0	22.5	35.3	184.0	197.6
2.4 Technical Risk Management	-	4.9	4.9	33.2	-	-	-	33.2	38.0
2.5 Program Reviews	56.7	62.9	119.6	20.5	85.5	6.2	16.0	128.2	247.8
3 Design & Fabrication	**120.7**	**183.7**	**304.4**	**625.6**	**1,409.5**	**198.8**	**66.9**	**2,300.7**	**2,605.2**
3.1 Structure	83.4	104.3	187.7	180.3	412.7	-	-	592.9	780.6
3.5 Support Electronics	14.9	51.8	66.7	245.1	563.9	-	-	809.0	875.8
3.6 Software	22.4	27.6	50.0	67.2	183.4	194.2	24.4	469.2	519.2
3.7 GSE	-	-	-	133.0	249.5	4.6	42.5	429.6	429.6
4 Integration & Validation	**18.2**	**81.3**	**99.5**	**98.8**	**352.5**	**926.7**	**130.0**	**1,507.9**	**1,607.4**
4.1 Subsystem Integration	-	-	-	56.8	95.5	20.3	-	172.6	172.6
4.2 Flight Model Integration	10.6	10.6	21.3	11.8	29.6	601.9	75.0	718.3	739.6
4.3 Carrier Integration	7.5	70.6	78.2	30.2	227.4	304.5	55.0	617.0	695.2
5 Operations	-	**3.1**	**3.1**	**19.9**	**36.2**	**55.7**	**399.6**	**511.4**	**514.4**
5.1 On-Orbit Experiment Procedures	-	3.1	3.1	3.1	6.5	41.0	15.1	65.6	68.7
5.2 GSFC, JSC, & KSC Operations	-	-	-	16.9	29.7	14.7	318.4	379.6	379.6
5.3 Post-Flight Data Analysis & Evaluation	-	-	-	-	-	-	66.1	66.1	66.1
MIT and PSI Total:	**350.8**	**448.2**	**799.0**	**1,047.5**	**2,241.0**	**1,472.7**	**774.8**	**5,536.1**	**6,335.1**
JPL									
1 Management	**7.2**	**5.4**	**12.6**	**110.4**	**219.3**	**129.3**	**18.3**	**477.3**	**489.9**
1.4 JPL & Subcontractor Management	7.2	5.4	12.6	69.1	94.0	65.5	18.3	246.9	259.5
1.5 Quality	-	-	-	41.3	125.3	63.8	-	230.4	230.4
2 System Engineering	**10.0**	**15.0**	**25.0**	**40.0**	**70.0**	**40.0**	-	**150.0**	**175.0**
2.5 Program Reviews	10.0	15.0	25.0	40.0	70.0	40.0	-	150.0	175.0
3 Design & Fabrication	**245.9**	**272.9**	**518.8**	**2,082.4**	**1,378.2**	-	-	**3,460.5**	**3,979.3**
3.2 Isolation	41.8	52.1	93.9	299.0	298.7	-	-	597.7	691.6
3.3 Opto-Mechanical Systems	61.7	111.2	172.9	462.6	531.2	-	-	993.8	1,166.7
3.4 Optics & Metrology	83.4	67.0	150.4	574.7	457.3	-	-	1,032.0	1,182.4
3.5 Support Electronics	37.5	24.0	61.5	452.5	12.1	-	-	464.6	526.1
3.6 Software	21.5	18.6	40.1	293.5	78.9	-	-	372.4	412.5
4 Integration & Validation	-	-	-	-	**448.5**	**599.4**	-	**1,048.0**	**1,048.0**
4.1 Subsystem Integration	-	-	-	-	448.5	488.7	-	937.2	937.2
4.2 Flight Model Integration	-	-	-	-	-	110.8	-	110.8	110.8
5 Operations	-	-	-	-	-	-	**133.8**	**133.8**	**133.8**
5.1 On-Orbit Experiment Procedures	-	-	-	-	-	-	44.6	44.6	44.6
5.2 GSFC, JSC, & KSC Operations	-	-	-	-	-	-	44.6	44.6	44.6
5.3 Post-Flight Data Analysis & Evaluation							44.6	44.6	44.6
JPL Total:	**263.1**	**293.3**	**556.4**	**2,232.7**	**2,115.9**	**768.8**	**152.2**	**5,269.6**	**5,826.0**
TOTAL PROJECT	**613.9**	**741.5**	**1,355.4**	**3,280.3**	**4,357.0**	**2,241.5**	**927.0**	**10,805.7**	**12,161.1**

Attachment C: The table below show costs broken out by WBS elements and categories. Similar to Attachment B, MIT and PSI costs are combined, with JPL costs shown separately. The last section of the table shows the program summary. Direct Labor represents the actual personnel salaries. Employee benefits and Overhead is applied to direct labor. Indirect costs are applied to labor, employee benefits and overhead, tra and materials and services. In the MIT and PSI table, fee is 9% of the total PSI costs for each WBS element. In the JPL table, fee is 1% of direct labor, travel, and material.

COST CATEGORIES	Management					WBS-1	System Engineering					WBS-2	Design & Fabrication							WBS-3	Integ. & Validation			WBS-4	Operations			WBS-5	GRAND
	1.1	1.2	1.3	1.4	1.5	TOTAL	2.1	2.2	2.3	2.4	2.5	TOTAL	3.1	3.2	3.3	3.4	3.5	3.6	3.7	TOTAL	4.1	4.2	4.3	TOTAL	5.1	5.2	5.3	TOTAL	TOTALS
MIT and PSI																													
PHASE B																													
Direct Labor	4.9	6.6	1.5	14.7	4.1	31.8	15.1	25.2	4.6	1.6	26.6	73.2	52.3	-	-	-	22.6	17.0	-	91.9	-	7.2	20.7	27.9	1.0	-	-	1.0	225.8
Employee Benefits and OH	2.1	4.4	0.7	16.4	4.6	28.1	14.6	13.1	5.2	1.8	25.9	60.5	37.5	-	-	-	25.2	18.9	-	81.6	-	8.0	23.0	31.1	1.2	-	-	1.2	202.5
Travel	11.3	-	-	-	-	11.3	-	-	-	-	31.1	31.1	-	-	-	-	-	-	-	-	-	-	7.8	7.8	-	-	-	-	50.2
Materials and Services	3.2	4.3	0.5	-	-	8.0	0.1	29.1	-	-	0.9	30.1	54.7	-	-	-	-	-	-	54.7	-	-	4.5	4.5	-	-	-	-	97.3
Indirect Costs	10.2	17.5	1.3	8.7	2.4	40.2	9.3	18.9	2.7	1.0	27.6	59.6	37.9	-	-	-	13.4	10.0	-	61.3	-	4.3	15.7	20.0	0.6	-	-	0.6	181.6
Fee	-	1.0	-	3.6	1.0	5.5	2.9	0.8	1.1	0.4	7.4	12.6	5.3	-	-	-	5.5	4.1	-	14.9	-	1.8	6.5	8.2	0.3	-	-	0.3	41.5
MIT and PSI Phase B	31.6	33.8	3.9	43.4	12.1	124.9	42.0	87.0	13.6	4.9	119.6	267.1	187.7	-	-	-	66.7	50.0	-	304.4	-	21.3	78.2	99.5	3.1	-	-	3.1	799.0
PHASE C/D																													
Direct Labor	56.8	29.8	9.2	65.8	12.7	174.3	-	150.9	62.4	8.2	26.1	247.5	74.4	-	-	-	133.6	157.2	32.4	397.6	33.8	161.7	161.7	357.2	22.7	83.8	28.5	135.0	1,311.6
Employee Benefits and OH	24.7	13.0	4.0	73.3	9.3	124.3	-	71.1	69.5	9.1	22.8	172.5	62.5	-	-	-	148.9	175.0	36.0	422.3	26.3	166.1	179.8	372.2	13.6	82.6	12.4	108.5	1,199.7
Travel	34.0	-	-	-	-	34.0	-	-	-	-	36.8	36.8	-	-	-	-	-	-	-	-	7.8	37.5	63.0	108.3	-	88.5	-	88.5	267.6
Materials and Services	11.9	0.7	4.1	-	0.2	16.9	-	9.6	-	6.5	2.9	19.0	296.7	-	-	-	297.4	3.7	239.1	836.9	54.9	144.5	36.3	235.8	6.7	9.5	1.4	17.6	1,126.1
Indirect Costs	68.0	23.7	9.4	38.9	9.2	149.2	-	121.2	36.9	6.7	33.8	198.6	120.4	-	-	-	162.3	95.1	87.2	464.9	40.4	154.6	127.0	322.0	21.3	93.6	23.8	138.7	1,273.5
Fee	-	-	-	16.0	1.4	17.4	-	2.0	15.2	2.7	5.8	25.7	39.0	-	-	-	66.8	38.2	35.0	178.9	9.4	53.9	49.3	112.5	1.3	21.8	-	23.1	357.7
MIT and PSI Phase C/D	195.5	67.2	26.6	194.0	32.7	516.0	-	354.8	184.0	33.2	128.2	700.1	592.9	-	-	-	809.0	469.2	429.6	2,300.7	172.6	718.3	617.0	1,508.0	65.6	379.6	66.1	511.3	5,536.1
MIT and PSI Totals	227.2	101.0	30.5	237.4	44.8	640.9	42.0	441.9	197.6	38.0	247.8	967.2	780.6	-	-	-	875.7	519.2	429.6	2,605.1	172.6	739.6	695.2	1,607.4	68.7	379.6	66.1	514.4	6,335.1
JPL																													
PHASE B																													
Direct Labor	-	-	-	6.0	-	6.0	-	-	-	-	7.1	7.1	-	44.7	58.5	56.8	29.3	19.1	-	208.4	-	-	-	-	-	-	-	-	221.6
Employee Benefits and OH	-	-	-	5.9	-	5.9	-	-	-	-	7.1	7.1	-	44.3	58.0	56.3	29.0	18.9	-	206.6	-	-	-	-	-	-	-	-	219.6
Travel	-	-	-	-	-	-	-	-	-	-	9.5	9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.5
Materials and Services	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46.1	28.6	-	-	-	74.7	-	-	-	-	-	-	-	-	74.7
Indirect Costs	-	-	-	0.6	-	0.6	-	-	-	-	1.2	1.2	-	4.4	9.2	7.8	2.9	1.9	-	26.3	-	-	-	-	-	-	-	-	28.0
Fee	-	-	-	0.1	-	0.1	-	-	-	-	0.2	0.2	-	0.4	1.0	0.9	0.3	0.2	-	2.8	-	-	-	-	-	-	-	-	3.1
JPL Phase B	-	-	-	12.6	-	12.6	-	-	-	-	25.0	25.0	-	93.9	172.9	150.4	61.5	40.1	-	518.8	-	-	-	-	-	-	-	-	556.4
PHASE C/D																													
Direct Labor	-	-	-	117.6	109.7	227.2	-	-	-	-	57.1	57.1	-	191.3	193.7	144.3	115.9	159.2	-	804.3	370.0	48.0	-	418.0	15.7	15.7	15.7	47.1	1,553.8
Employee Benefits and OH	-	-	-	116.5	108.7	225.2	-	-	-	-	56.6	56.6	-	189.6	191.9	143.0	114.8	157.8	-	797.1	366.7	47.5	-	414.2	15.5	15.5	15.5	46.6	1,539.8
Travel	-	-	-	-	-	-	-	-	-	-	28.4	28.4	-	-	-	-	-	-	-	-	37.8	9.5	-	47.3	11.0	11.0	11.0	33.1	108.8
Materials and Services	-	-	-	-	-	-	-	-	-	-	-	-	-	180.7	541.4	672.4	204.0	35.0	-	1,633.5	110.7	-	-	110.7	-	-	-	-	1,744.2
Indirect Costs	-	-	-	11.7	10.9	22.6	-	-	-	-	7.0	7.0	-	32.4	59.4	64.2	26.7	18.4	-	201.2	46.8	5.2	-	52.0	2.1	2.1	2.1	6.2	289.0
Fee	-	-	-	1.2	1.1	2.3	-	-	-	-	0.9	0.9	-	3.7	7.4	8.2	3.2	1.9	-	24.4	5.2	0.6	-	5.8	0.3	0.3	0.3	0.8	34.1
JPL Phase C/D	-	-	-	246.9	230.4	477.3	-	-	-	-	150.0	150.0	-	597.7	993.8	1,032.0	464.6	372.4	-	3,460.5	937.2	110.8	-	1,048.0	44.6	44.6	44.6	133.8	5,269.6
JPL Totals	-	-	-	259.5	230.4	489.9	-	-	-	-	175.0	175.0	-	691.6	1,166.7	1,182.4	526.1	412.5	-	3,979.3	937.2	110.8	-	1,048.0	44.6	44.6	44.6	133.8	5,826.0
Total Program																													
PHASE B																													
Direct Labor	4.9	6.6	1.5	20.7	4.1	37.8	15.1	25.2	4.6	1.6	33.7	80.3	52.3	44.7	58.5	56.8	51.9	36.1	-	300.3	-	7.2	20.7	27.9	1.0	-	-	1.0	447.4
Employee Benefits and OH	2.1	4.4	0.7	22.3	4.6	34.1	14.6	13.1	5.2	1.8	33.0	67.6	37.5	44.3	58.0	56.3	54.2	37.8	-	288.2	-	8.0	23.0	31.1	1.2	-	-	1.2	422.1
Direct Travel	11.3	-	-	-	-	11.3	-	-	-	-	40.6	40.6	-	-	-	-	-	-	-	-	-	-	7.8	7.8	-	-	-	-	59.7
Direct Materials	3.2	4.3	0.5	-	-	8.0	0.1	29.1	-	-	0.9	30.1	54.7	-	46.1	28.6	-	-	-	129.4	-	-	4.5	4.5	-	-	-	-	172.0
Indirect Costs	10.2	17.5	1.3	9.3	2.4	40.8	9.3	18.9	2.7	1.0	28.8	60.7	37.9	4.4	9.2	7.8	16.3	11.9	-	87.6	-	4.3	15.7	20.0	0.6	-	-	0.6	209.6
Fee	-	1.0	-	3.6	1.0	5.6	2.9	0.8	1.1	0.4	7.6	12.8	5.3	0.4	1.0	0.9	5.8	4.3	-	17.8	-	1.8	6.5	8.2	0.3	-	-	0.3	44.6
Total Program Phase B	31.6	33.8	3.9	56.0	12.1	137.5	42.0	87.0	13.6	4.9	144.6	292.1	187.7	93.9	172.9	150.4	128.2	90.1	-	823.2	-	21.3	78.2	99.5	3.1	-	-	3.1	1,355.4
PHASE C/D																													
Direct Labor	56.8	29.8	9.2	183.3	122.4	401.5	-	150.9	62.4	8.2	83.2	304.7	74.4	191.3	193.7	144.3	249.5	316.4	32.4	1,201.9	403.8	209.6	161.7	775.2	38.4	99.5	44.2	182.0	2,865.3
Employee Benefits and OH	24.7	13.0	4.0	189.8	118.0	349.5	-	71.1	69.5	9.1	79.4	229.1	62.5	189.6	191.9	143.0	263.7	332.7	36.0	1,219.4	393.0	213.6	179.8	786.4	29.1	98.1	27.9	155.2	2,739.5
Direct Travel	34.0	-	-	-	-	34.0	-	-	-	-	65.2	65.2	-	-	-	-	-	-	-	-	45.7	47.0	63.0	155.6	11.0	99.5	11.0	121.6	376.3
Direct Materials	11.9	0.7	4.1	-	0.2	16.9	-	9.6	-	6.5	2.9	19.0	296.7	180.7	541.4	672.4	501.5	38.7	239.1	2,470.5	165.6	144.5	36.3	346.4	6.7	9.5	1.4	17.6	2,870.4
Indirect Costs	68.0	23.7	9.4	50.6	20.1	171.8	-	121.2	36.9	6.7	40.9	205.6	120.4	32.4	59.4	64.2	188.9	113.5	87.2	666.1	87.2	159.8	127.0	374.0	23.4	95.6	25.9	144.9	1,562.4
Fee	-	-	-	17.2	2.5	19.6	-	2.0	15.2	2.7	6.7	26.6	39.0	3.7	7.4	8.2	70.0	40.2	35.0	203.3	14.6	54.5	49.3	118.3	1.6	22.1	0.3	23.9	391.7
Total Program Phase C/D	195.5	67.2	26.6	440.9	263.1	993.3	-	354.8	184.0	33.2	278.2	850.1	592.9	597.7	993.8	1,032.0	1,273.6	841.6	429.6	5,761.2	1,109.8	829.1	617.0	2,555.9	110.2	424.2	110.7	645.2	10,805.7
Program Totals	227.2	101.0	30.5	496.9	275.2	1,130.8	42.0	441.9	197.6	38.0	422.8	1,142.2	780.6	691.6	1,166.7	1,182.4	1,401.8	931.7	429.6	6,584.4	1,109.8	850.3	695.2	2,655.4	113.3	424.2	110.7	648.2	12,161.1

CONTRACT PRICING PROPOSAL COVER SHEET

1. SOLICITATION/CONTRACT/MODIFICATION NO.
AO W-OAST-1-92

FORM APPROVED
OMB NO.
9000-0013

NOTE: This form is used in contract actions if submission of cost or pricing data is required. (See FAR 15.804-6(b))

2. NAME AND ADDRESS OF OFFEROR (Include ZIP Code)
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

DUNS: 00-142-5594

3A. NAME AND TITLE OF OFFEROR'S POINT OF CONTACT
Patricia Greer
Coordinator

3B. TELEPHONE NO.
(617)253-3864

4. TYPE OF CONTRACT ACTION (Check)

X	A. NEW CONTRACT		D. LETTER CONTRACT
	B. CHANGE ORDER		E. UNPRICED ORDER
	C. PRICE REVISION/ REDETERMINATION		F. OTHER (Specify)

5. TYPE OF CONTRACT (Check)
[ ] FFP [ ] CPFF [ ] CPIF [ ] CPAF
[ ] FPI [X] OTHER (Specify) Cost Reimbursement

6. PROPOSED COST (A+B=C)

A. COST	B. PROFIT/FEE	C. TOTAL
$6,335,100	$0	$6,335,100

7. PLACE(S) AND PERIOD(S) OF PERFORMANCE
Massachusetts Institute of Technology, Department of
Cambridge, MA 02139

8. List and reference the identification, quantity and total price proposed for each contract line item. A line item cost breakdown supporting this recap is required unless otherwise specified by the Contracting Officer. (Continue on reverse, and then on plain paper, if necessary. Use same headings.)

A. LINE ITEM NO.	B. IDENTIFICATION	C. QUANTITY	D. TOTAL PRICE	E. REF.
	See attached proposal		$	

9. PROVIDE NAME, ADDRESS AND TELEPHONE NUMBER FOR THE FOLLOWING (If available)

A. CONTRACT ADMINISTRATION OFFICE
Office of Naval Research
495 Summer Street, Room 103
Boston, MA 02210-2109

(617) 451-4666 Mr. George Kilbride

B. AUDIT OFFICE
Defense Contract Audit Agency (DCAA)
238 Main Street, Suite 311
Cambridge, MA 02142

(617) 252-1028 Mr. Paul Catanzano

10. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS WORK? (If "Yes", identify)
[ ] YES [X] NO

11A. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT? (If "Yes", complete Item 11B)
[X] YES [ ] NO

11B. TYPE OF FINANCING (✓ one)
[X] ADVANCE PAYMENTS [ ] PROGRESS PAYMENTS
[ ] GUARANTEED LOANS

12. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR THE SAME OR SIMILAR ITEMS WITHIN THE PAST 3 YEARS? (If "Yes", identify item(s), customer(s) and contract number(s))
[ ] YES [X] NO

13. IS THIS PROPOSAL CONSISTENT WITH YOUR ESTABLISHED ESTIMATING AND ACCOUNTING PRACTICES AND PROCEDURES AND FAR PART 31 COST PRINCIPLES? (If "No", explain)
[X] YES [ ] NO

14. COST ACCOUNTING STANDARDS BOARD (CASB) DATA (Public Law 91-379 as amended and FAR PART 30)

A. WILL THIS CONTRACT ACTION BE SUBJECT TO CASB REGULATIONS? (If "No", explain in proposal)
[X] YES [ ] NO

B. HAVE YOU SUBMITTED A CASB DISCLOSURE STATEMENT (CASB DS 1 or 2)? (If "Yes", specify in proposal the office to which submitted and if determined to be adequate)
[X] YES [ ] NO To ONR 7/23/86 (Update in Process)

C. HAVE YOU BEEN NOTIFIED THAT YOU ARE OR MAY BE IN NON-COMPLIANCE WITH YOUR DISCLOSURE STATEMENT OR COST ACCOUNTING STANDARDS? (If "Yes", explain in proposal)
[ ] YES [X] NO

D. IS ANY ASPECT OF THIS PROPOSAL INCONSISTENT WITH YOUR DISCLOSED PRACTICES OR APPLICABLE COST ACCOUNTING STANDARDS? (If "Yes", explain in proposal)
[ ] YES [X] NO

This proposal is submitted in response to the RFP, contract, modification, etc., in Item 1 and reflects our best estimates and/or actual costs as of this date and conforms with the instructions in FAR 15.804-6(b) (2), Table 15-2. By submitting this proposal, the offeror, if selected for negotiation, grants the contracting officer or an authorized representative the right to examine, at any time before award, those books, records, documents and other types of factual information, regardless of form or whether such supporting information is specifically referenced or included in the proposal as the basis for pricing, that will permit an adequate evaluation of the proposed price.

15. NAME AND TITLE (Type)
David J. Harrigan
Associate Director

16. NAME OF FIRM
Massachusetts Institute of Technology

17. SIGNATURE
David J. Harrigan

18. DATE OF SUBMISSION
2/10/95

NSN 7540-01-142-9845
*U.S. GPO: 1987-181-247-6015
1411-102
STANDARD FORM 1411 (REV. 7-87)
Prescribed by GSA
FAR (48 CFR) 53.215-2(c)

CONTRACT PRICING PROPOSAL COVER SHEET

1. SOLICITATION/CONTRACT/MODIFICATION NO.

FORM APPROVED
OMB NO. 3000-0013

NOTE: This form is used in contract actions if submission of cost or pricing data is required. *(See FAR 15.804-6(b))*

2. NAME AND ADDRESS OF OFFEROR *(Include ZIP Code)*

PAYLOAD SYSTEMS INC.
270 Third Street
Cambridge, MA 02142

3A. NAME AND TITLE OF OFFEROR'S POINT OF CONTACT

Pamela A. Moriarty, Controller

3B. TELEPHONE NO.

(617) 868-8086 ext. 19

4. TYPE OF CONTRACT ACTION (Check)

- [X] A. NEW CONTRACT
- [ ] B. CHANGE ORDER
- [ ] C. PRICE REVISION/ REDETERMINATION
- [ ] D. LETTER CONTRACT
- [ ] E. UNPRICED ORDER
- [ ] F. OTHER (Specify)

5. TYPE OF CONTRACT

- [ ] FFP
- [X] CPFF
- [ ] CPIF
- [ ] CPAF
- [ ] FPI
- [ ] OTHER (Specify)

6. PROPOSED COST (A+B=C)

A. COST	B. PROFIT/FEE	C. TOTAL
$ 4,435,644	$ 399,208	$ 4,834,852

7. PLACE(S) AND PERIOD(S) OF PERFORMANCE

270 Third Street, Cambridge, MA 02142
Period of Performance: 1 June 1995 - 31 Dec. 1999 (Phase-B and C/D)

8. List and reference the identification, quantity and total price proposed for each contract line item. A line item cost breakdown supporting this recap is required unless otherwise specified by the Contracting Officer. *(Continue on reverse and then on plain paper, if necessary. Use same headings.)*

A. LINE ITEM NO	B. IDENTIFICATION	C. QUANTITY	D. TOTAL PRICE	E. REF.
001	Payload Systems Inc. Proposal No. 92-P028 entitled: Stellar Interferometer Tracking Experiment (SITE)	1 Lot	4,834,852	See Attached

9. PROVIDE NAME, ADDRESS, AND TELEPHONE NUMBER FOR THE FOLLOWING *(If available)*

A. CONTRACT ADMINISTRATION OFFICE

Defence Contract Administration Services
495 Summer Street
Boston, MA 02110 Tel. (617) 451-4180

B. AUDIT OFFICE

Defence Contract Audit Agency, Boston Branch
Thomas P. O'Neil Federal Building
10 Causeway St., Rm. 253, Boston, MA 02222 Tel. (617) 565-7352

10. WILL YOU REQUIRE THE USE OF ANY GOVERMENT PROPERTY IN THE PERFORMANCE OF THIS WORK? *(If "Yes," identify)*

- [ ] YES
- [X] NO

11A. DO YOU REQUIRE GOVERMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED *(If "Yes," complete item 11B)*

- [X] YES
- [ ] NO

11B. TYPE OF FINANCING (if one)

- [ ] ADVANCE PAYMENTS
- [X] PROGRESS PAYMENTS
- [ ] GUARANTEED LOANS

12. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR THE SAME OR SIMILAR ITEMS WITHIN THE PAST 3 YEARS? *(If "Yes," identify item(s), customer(s) and contract number(s))*

- [ ] YES
- [X] NO

13. IS THIS PROPOSAL CONSISTENT WITH YOUR ESTABLISHED ESTIMATING AND ACCOUNTING PRACTICES AND PROCEDURES AND FAR PART 31 COST PRINCIPALS? *(If "No," explain)*

- [X] YES
- [ ] NO

14. COST ACCOUNTING STANDARDS BOARD (CASB) DATA *(Public Law 91-379 as amended and FAR PART 30)*

A. WILL THIS CONTRACT ACTION BE SUBJECT TO CASB REGULATIONS *(If "No," explain in proposal)*

- [X] YES
- [ ] NO

B. HAVE YOU SUBMITTED A CASB DISCLOSURE STATEMENT (CASB DS-1 or 2)? *(If "Yes," specify in proposal the office to which submitted and if determined to be adequate)*

- [ ] YES
- [X] NO

C. HAVE YOU BEEN NOTIFIED THAT YOU ARE OR MAY BE IN NONCOMPLIANCE WITH YOUR DISCLOSURE STATEMENT OR COST ACCOUNTING STANDARDS? *(If "Yes," explain in proposal)*

- [ ] YES
- [X] NO

D. IS ANY ASPECT OF THIS PROPOSAL INCONSISTENT WITH YOUR DISCLOSED PRACTICES OR APPLICABLE COST ACCOUNTING STANDARDS? *(If "Yes," explain in proposal)*

- [ ] YES
- [X] NO

This proposal is submitted in response to the RFP contract, modification, etc. in item 1 and reflects our best estimates and/or actual cost as of this date and conforms with the instructions in FAR 15.804-6(b) (2), Table 15-2. By submitting this proposal, the offeror, if selected for negotiation, grants the contracting officer or an authorized representative the right to examine, at any time before the award, those books, records, documents and other types of factual information regardless of form or whether such supporting information is specifically referenced or included in the proposal as the basis for pricing, that will permit an adequate evaluation of the proposed price.

15. NAME AND TITLE *(Type)*

Pamela A. Moriarty, Controller

16. NAME OF FIRM

PAYLOAD SYSTEMS INC.

17. SIGNATURE

Pamela A. Moriarty

18. DATE OF SUBMISSION

7 February 1995

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109 8099
(818) 354-4321

JPL

January 20, 1995
DIR/TAP-95-027

Prof. Edward Crawley
Massachusetts Institute of Technology
Space Engineering Research Center
Building 37, Room 351
77 Massachusetts Avenue
Cambridge, MA 02139

Subject: Letter of Commitment

Reference: National Aeronautics and Space Administration In-Step Technology Experiments Program Solicitation W-OAST-1-92 Phase B Proposal: Stellar Interferometry Technology Experiment (SITE), MIT February, 1995

Dear Prof. Crawley:

The Jet Propulsion Laboratory (JPL) is pleased to convey its intent to participate in the referenced effort. It is our understanding that MIT will submit a proposal for the referenced effort to the National Aeronautics and Space Administration.

The proposed experiment is suitable for a mission on the Space Shuttle to demonstrate overall technology readiness for space optical interferometry. This will be done by developing and flying, in the Shuttle cargo bay, a 4-m baseline optical interferometer capable of acquiring and stabilizing starlight interference fringes at the 25 nanometer RMS level. SITE will also produce on-orbit engineering data leading to a quantitative understanding of the benefits of various "layers" of controlled structures technology (viz., vibration isolation, high bandwidth active optical control, and structural vibration damping) for future space interferometry missions. Finally, SITE will serve to flight validate modeling tools like IMOS (Integrated Modeling of Advanced Optical Systems) which will be invaluable to the next generation of precision space optical systems.

JPL will, on a best-efforts basis, deliver to MIT or its designated subcontractor: (i) SITE interferometer instrument flight hardware (i.e., three optical benches populated with optical, optomechanical, and laser metrology components comprising the instrument) for integration with the SITE structure; (ii) SITE isolation system flight hardware; (iii) SITE instrument control flight software; (iv) SITE isolator engineering model; (v) mass simulators of the instrument optical benches; (vi) SITE IMOS mathematical model for performance simulation; (vii) relevant design and test documentation. JPL will also participate in flight data analysis and reporting. These tasks and deliverables, along with their positions in the overall SITE WBS, are detailed in the referenced Phase B proposal (which is attached).

JPL will prepare a proposal to MIT on a non-exclusive basis to formalize JPL's estimated costs as well as the scope of work. JPL's initial cost estimate for this effort is $556.4K for Phase B with an estimated period of performance of 9 months. JPL's cost estimate for phase C/D is $5269.6K with a period of performance of 45 months.

Please be advised that JPL is an operating division of the California Institute of Technology (Caltech) and as such, all work shall be performed under the terms and conditions of NASA/Caltech Contract NAS7-1260. Government audit is performed on a continuing basis by a Defense Contract Audit Agency resident team.

Please contact Dr. Michael Shao at (818) 354-7834 or Dr. Robert Laskin at (818) 354-5086, if you have any questions on technical aspects of this effort; or Mr. Michael S. Jameson at (818) 354-8390 for contractual matters.

Sincerely,

R. Rhoads Stephenson/for

James A. Evans
Director for Technology and
Applications Programs

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13. ABSTRACT (Maximum 200 words)
SITE, A Hitchhiker-class experiment, is a two-aperture stellar interferometer located in the Space Shuttle payload bay. It consists of three optical benches kinematically mounted inside a 4-meter precision truss structure. Starlight is collected through the apertures and an interference fringe pattern is generated. The amplitude and phase of the fringes provide the information essential for performing imaging and astrometry. To obtain precise fringe measurements, SITE will employ active optics for wavefront-tilt control and reactionless optical delay lines for active pathlength control. In addition, isolation and vibration suppression will attenuate vibrations caused by payload bay and internal disturbances which would otherwise blur the interference pattern. The mission will quantify the performance and cost benefits of the various technologies that will enable or enhance space-based interferometry.

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