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Mission Planning for the Lidar In Space Technology Experiment

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Abstract

Developing a mission planning system for a Space Shuttle mission is a complex procedure. Several months of preparation are required to develop a plan that optimizes science return during the short operations time frame. Further complicating the scenario is the necessity to schedule around crew activities and other payloads which share Orbiter resources. SpaceTec, Inc. developed the mission planning system for the Lidar In Space Technology Experiment, or LITE, which flew on Space Shuttle mission STS-64 in September of 1994. SpaceTec used a combination of off-the-shelf and in-house developed software to analyze various mission scenarios both pre-mission and real-time during the flight. From this analysis, SpaceTec developed a comprehensive mission plan that met the mission objectives.

Purpose

The LITE mission was originally conceived as a technology demonstration of a spaceborne lidar. As such, the shuttle orbit was designed, as detailed in the original LITE Payload Integration Plan[2], to meet the minimum technology objectives.* Lidar in space could be proven technically feasible as an investigative tool by an orbit with a minimum inclination of 28°, altitudes ranging from 115 nautical miles to 160 nautical miles, and a launch any time of day. As the opportunity to expand the science value of the LITE mission became apparent, the need arose to analyze numerous mission scenarios. Additionally, the decreasing likelihood of available funding for a reflight of the LITE payload made opportunistic planning necessary. SpaceTec provided both the data and the analysis to the mission scientists throughout the development of the LITE mission plan.†

Flight Design

The initial inclination chosen by the Space Shuttle Program for the LITE mission was 28°. This inclination could not provide the global coverage necessary for proper validation of the LITE data set. As shown in Figure 1, most of the ground correlative sites were located north of 28°. Shuttle ephemeris ground tracks were generated and overlaid on maps of the correlative ground stations to demonstrate this point. The data sets were digitized and a statistical analysis was done that reflected the large increases in ground site coverage at the higher inclinations. This data was used in the development of presentation materials for meetings at Johnson Space Center (JSC) and NASA headquarters in which the launch inclination was debated with mission management. Eventually, the launch inclination was increased to 57°, reflecting a significant increase in the global coverage as shown in Figure 2.

Ground track coverage created for the new inclination showed the sites now acquired by the higher inclination were in sunlight for many of the shuttle overflights. This was unacceptable for calibration due to the high signal-to-noise ratio associated with a daylight pass. Through the generation of multiple data sets at different launch times, it was demonstrated that a launch window could be designed that met all of the science objectives at the 57° inclination. Even though payloads rarely influence the selection of a launch window, a 2½ hour evening launch window that met the LITE requirements was approved. SpaceTec generated and provided to JSC flight designers the digital launch window data used to determine the launch time for any day of the year. Figure 3 shows this data plotted on the standard JSC launch window graph.

During the flight design stage, the shuttle altitude was varied multiple times to accommodate other

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*The LITE PIP in its final form reflects the implementation of numerous change requests discussed in this text.

† For a description of the LITE mission from a science perspective, please reference McCormick, Patrick M., *Spaceborne Lidars.*[3]

possible payloads. An altitude of 140 nm., with a drop to 130 nm. toward the end of mission to accommodate landing opportunities, was chosen. For each iteration of the altitude, it was necessary to re-evaluate the mission plan. Modifications to the orbital altitude change the orbital period, thereby changing the timing and coverage of target areas.

Flight Planning

Due to power limitations onboard the Orbiter, the LITE payload was limited to a maximum of 45 hours of lasing. In order for this data to be quality science data, several issues had to be addressed and documented. SpaceTec was responsible for implementing these requirements in the Flight Planning Annex, Annex 2 Part II.[1] Some of these requirements included constraints on uncertainty in shuttle pointing, payload bay contamination, sun glint, and moon glint. Special science experiments designed to meet objectives of lidar in space were included in the development of the LITE flight plan requirements. These included shuttle cross-track maneuvers, landmark track maneuvers, multiscatters, and precise ground overflights. Cross-track maneuvers, performed at 2°/second, were the fastest shuttle maneuvers ever performed on primary jets. During the landmark track maneuver, the laser footprint was stationed at the same point on the surface for about 1½ minutes by varying the maneuver rate of the shuttle as it over flew the target area. The maneuvers were used to study wind and wave interaction. For the precision overflights, mission planners interacted with mission scientists and JSC flight controllers in real time to ensure the ground instrumentation was placed in the exact location of the LITE footprint. During the multiscatter experiment, the instrument's aperture wheel was continuously rotated through its four positions to study characteristics of cloud layers. All of these requirements were implemented through a series of working groups with mission scientists, engineers, and JSC flight planners. During the flight, immense coordination was required to guarantee the success of these special experiments.

Target Databases

Limited to 45 hours of lasing, the LITE team had to be selective about the location in which operations took place. Ground track plots provided data to make a preliminary assessment. With numerous global science interests and several operational constraints, such as lighting conditions and crew availability, ground track plots were not a sufficient analysis tool. A software solution was developed that involved creation of several databases in which comparative studies could be made. Mission scientists provided maps depicting areas of interest to a particular science objective. Figure 4 is an example of areas where cloud studies could likely be performed. These areas were then digitized into electronic site databases and compared against ephemeris data generated from an orbit propagator.[‡] Coincidences were flagged with relevant information such as lighting condition, crew availability, site priority, and conflicts with other payloads. Mission scientists were able to make educated scheduling decisions from this information. Figure 5 shows how overflights of ground-based lidar correlative sites were evaluated by the same method. By using this analysis tool, the 45 hours of lasing time were scheduled with the highest probability of mission success.

Data Take Profile

In order to graphically display the LITE flight plan requirements, SpaceTec developed the LITE Data Take Profile. (see Figure 6) This timeline displayed several layers of information on a mission elapsed time scale. The orbit number, crew sleep cycle, other payload operations, and the LITE schedule of special experiments and data takes were displayed. The LITE high rate data was recorded onboard on tapes capable of storing five hours of data each. Using the data take profile, a tape change-out schedule during the crew awake cycle could be graphically manipulated. The data take profile provided a quick, one-page overview of the entire mission, including shift hand-over times for the operations team. Developed in a layered CAD environment, the data take profile was easily modified when changes were necessary. In addition to providing a mission overview, the data take profile was also used to supply LITE flight plan requirements to the JSC flight planners.

Timeline Data

During the LITE mission flight phase, SpaceTec mission planners provided continuous, updated data to support timeline replanning. Much of the scheduled LITE data taking was synchronized with sunset or sunrise times. Any change to the scheduled launch

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[‡] *Satellite Tool Kit (STK)* by Analytical Graphics and the module *High Precision Orbit Propagator (HPOP)* by Microcosm proved invaluable to mission planners. The latest versions of these software tools can now perform the indicated tasks with minimal user customization.

time would result in necessary tweaking to the data taking times. The longer the launch slip within the launch window, the more significant the changes to the data take timing. The Shuttle altitude was also of prime importance to the LITE command timeline. In order to digitize the lidar return signal in the correct portion of the atmosphere, the precise altitude must be known. The chances of an unexpected Shuttle altitude or launch time is high, so a procedure whereby this data could be provided promptly was required. Events such as Orbiter maneuvers and atmospheric drag also contribute to the necessity for routine updates to the command timeline. Using shuttle state vectors provided by JSC flight controllers, updated ephemeris data was generated using a high precision orbit propagator on a regular schedule. Software developed by SpaceTec then processed this ephemeris data and generated a subset of data containing information on altitude, sunset/sunrise, and equator crossing times. This information formed the basic data set required for the LITE command timeline.

Replan Database

There are many criteria for replanning. As mentioned before, unexpected deviations in the trajectory result in necessary changes to the timeline. For spaceborne atmospheric monitoring sensors such as lidar, weather phenomenon including hurricanes and natural events such as volcanoes require replanning. Whenever timeline changes are implemented, they require approval by mission control personnel. With few exceptions, inputs for timeline changes must be submitted hours before the scheduled event. To facilitate this process, SpaceTec developed a replan database. The database contained all of the planned LITE data taking operations, including times for cross-tracks, landmark tracks, overflights, tape change-outs, multiscatters, and lasing operations. Whenever changes were required, modifications could be made to the database. Database procedures would then electronically create a replan form which was submitted to mission control for approval. An example of the replan form for Flight Day 6 is shown in Figure 7. At a minimum, a preliminary and a final replan form were submitted once each day as part of the long-term planning process. With this frequency, an automated procedure proved invaluable.

Correlative Support

SpaceTec supported the LITE correlative program during the flight phase by providing updates to the crew photo plan and the correlative timeline. For each correlative ground site over-flown during a crew awake period, it was determined whether a photograph was possible. The look angle[§] was then calculated to assist the crew in locating the site. Information on other photographic opportunities of science interest was also provided. In order for ground sites to perform a correlative measurement, they required the time and lighting condition of the shuttle coincidence. Updates to this information were provided in two forms at scheduled intervals. One form was categorized alphabetically by the investigator's name. The other was organized sequentially by time. Both forms provided the shuttle orbit number and the coincident data take designator. The data was posted to an Internet server for access by principal investigators across the globe.

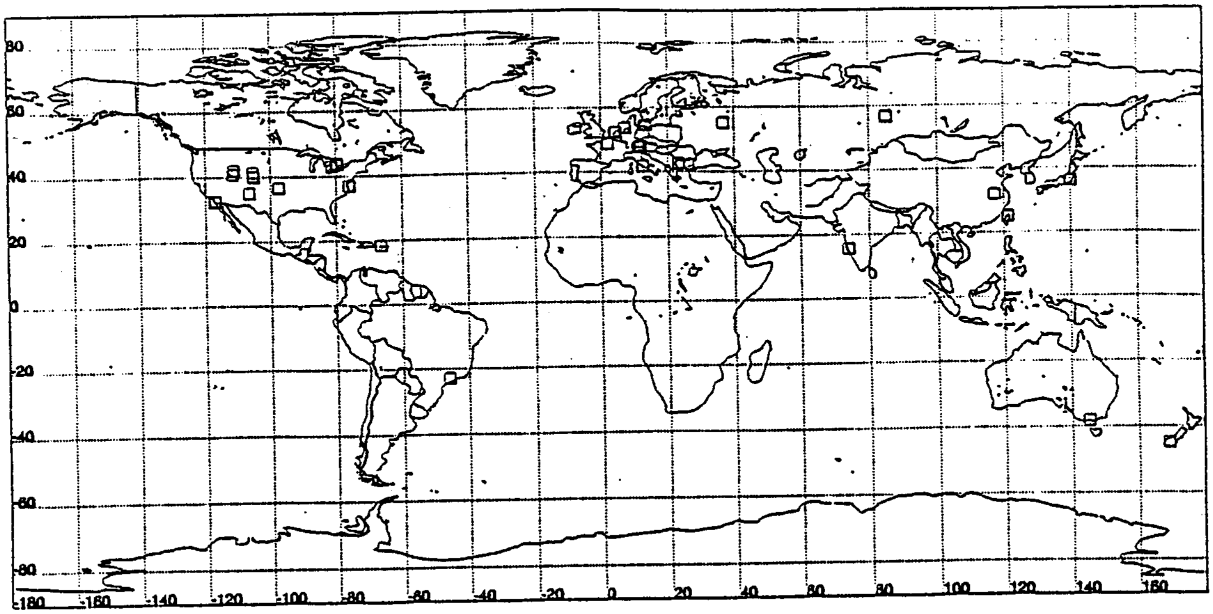
Conclusion

Much effort was expended in developing a comprehensive LITE pre-mission plan. In an environment as dynamic and unpredictable as the Shuttle, this plan becomes increasingly inaccurate during flight. However, the development of this extensive pre-mission plan assisted mission planners in defining the tools and processes required for a successful mission. During flight it is essential to have a mission plan that is updated continuously, instead of discarded entirely. With a mission plan as complex as that of LITE, automated procedures are required to perform this real-time updating. As the LITE data set demonstrates, a well conceived mission planning system is invaluable.

References

1. *LITE Flight Planning Annex*, Payload Integration Plan, Annex II Part 2, NASA NSTS#21149, Feb. 1994.
2. LITE Payload Integration Plan, NASA NSTS#21149, Rev. A, Sept. 1993.
3. McCormick, Patrick M., *Spaceborne Lidars*, The Review of Laser Engineering, vol. 23, no. 2, pp.175-179, The Laser Society of Japan, 1995.

[§] The look angle was defined as the angle in degrees from Earth nadir, referenced north or south of the ground track.



☐ Indicates a Correlative Ground Site

Figure 1 LITE Correlative Sites

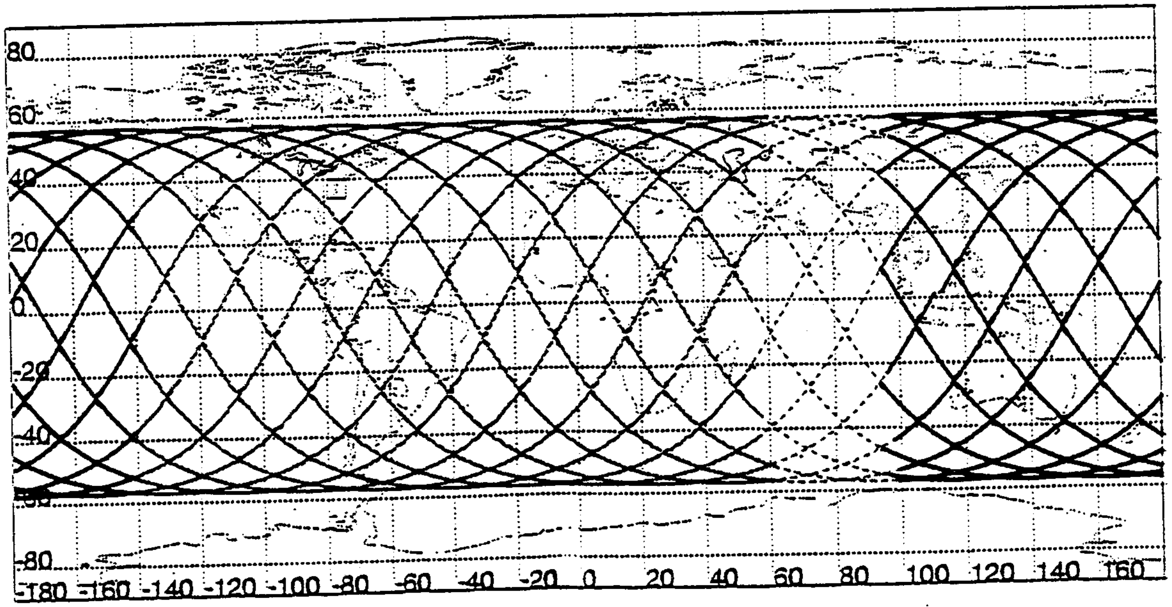


Figure 2 Typical 57° Inclination

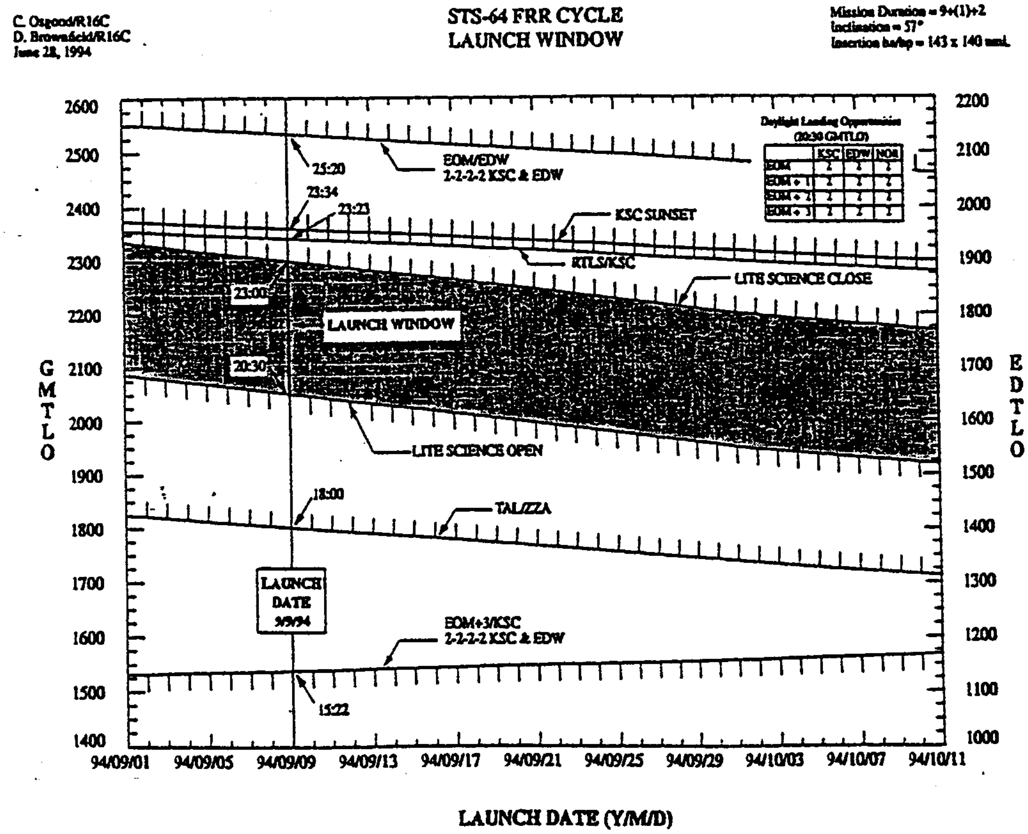


Figure 3 LITE Launch Window Curve

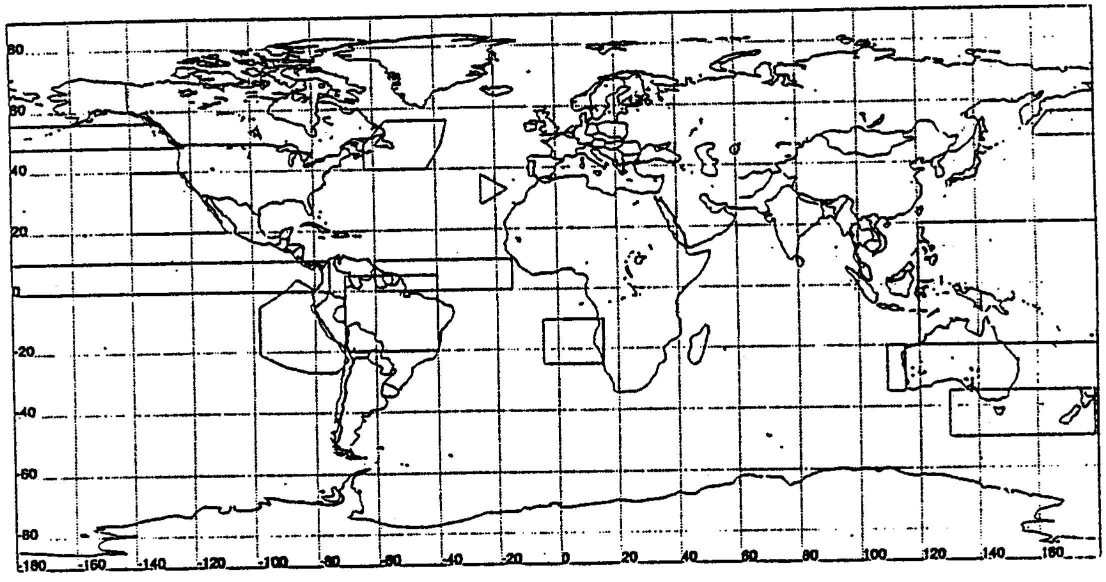
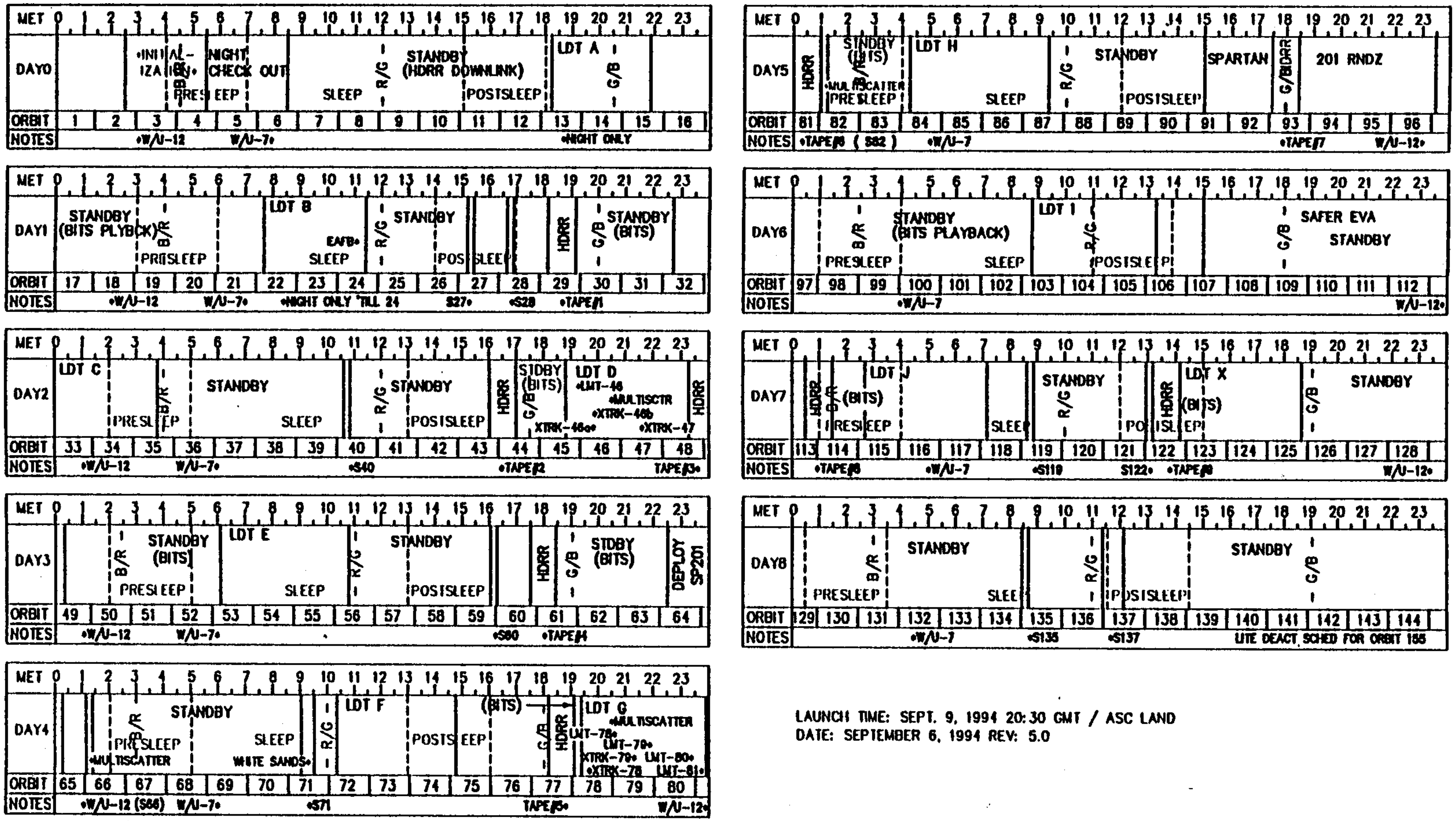


Figure 4 Cloud Target Areas

PASS No.	TAR No.	NAME	LOCATION	METSTART	LIGHTING			CREW CNFLCT	METEND	LIGHTING			DT No.
3	COR41	Meriwether, John W	USA	0/03:08:21.34	1	1	1		0/03:09:00.40	1	1	1	
24	COR25	Hu, Huanling	China	1/10:27:58.91	1	1	1	SLP2	1/10:28:34.01	1	1	1	
28	COR53	Shamanaev, V	Russia	1/16:38:45.14	1	1	1	POS2	1/16:39:00.57	1	1	1	
28	COR74	Zuev, Vladimir	Russia	1/16:38:45.14	1	1	1	POS2	1/16:39:00.57	1	1	1	
30	COR16	Flamant, Pierre	France	1/19:31:59.32	1	1	1		1/19:32:47.19	1	1	1	
34	COR18	Gardner, Chester S	USA	2/01:25:40.34	1	1	1		2/01:26:16.22	1	1	1	C
39	COR22	Hardesty	USA	2/09:15:40.62	0	0	0	SLP3	2/09:16:18.87	0	0	0	
39	COR91	Proffitt, Mike	U.S.	2/09:15:45.83	0	0	0	SLP3	2/09:16:23.86	0	0	0	
47	COR30	Khmelevtsov, S	Russia	2/21:05:41.50	1	1	1		2/21:06:12.14	0	1	1	D
55	COR41	Meriwether, John W	USA	3/09:09:41.89	0	0	0	SLP4	3/09:10:21.29	0	0	0	E
62	COR69	Weitkamp, C	Germany	3/19:23:45.86	1	1	1	SPRDP	3/19:24:53.33	1	1	1	
62	COR73	Zahn, Ulf Von	Germany	3/19:24:18.18	1	1	1	SPRDP	3/19:25:36.85	1	1	1	
64	COR73	Zahn, Ulf Von	Germany	3/22:30:31.13	1	1	1	SPRDP	3/22:31:50.39	0	1	1	
73	COR88	Davera, P.C.S.	India	4/11:37:33.75	1	1	1	SLP5	4/11:38:06.39	1	1	1	F
75	COR53	Shamanaev, V	Russia	4/14:51:23.18	1	1	1	POS5	4/14:52:00.59	1	1	1	F
75	COR74	Zuev, Vladimir	Russia	4/14:51:51.24	1	1	1	POS5	4/14:52:00.59	1	1	1	F
77	COR26	Jager, Horst	Germany	4/17:45:52.88	1	1	1		4/17:46:38.49	1	1	1	
77	COR25	Hu, Huanling	China	4/18:05:52.24	0	0	0		4/18:06:27.08	0	0	0	
92	COR53	Shamanaev, V	Russia	5/16:19:58.37	1	1	1		5/16:20:14.26	1	1	1	
92	COR74	Zuev, Vladimir	Russia	5/16:19:58.37	1	1	1		5/16:20:38.96	1	1	1	
96	COR37	McCormick	USA	5/22:05:45.18	1	1	1	SPRRN	5/22:06:21.89	1	1	1	
111	COR88	Davera, P.C.S.	India	6/20:58:59.32	0	0	0	SAFER	6/20:59:31.79	0	0	0	
112	COR69	Weitkamp, C	Germany	6/22:15:12.08	1	1	1	SAFER	6/22:16:19.46	1	1	1	
117	COR37	McCormick	USA	7/05:48:52.71	0	0	0	SLP8	7/05:49:29.07	0	0	0	J
119	COR25	Hu, Huanling	China	7/08:23:46.83	1	1	1	SLP8	7/08:24:21.67	1	1	1	
119	COR40	Menzies, R.	USA	7/08:48:57.87	0	0	0	SLP8	7/08:49:32.66	0	0	0	
128	COR69	Weitkamp, C	Germany	7/22:04:53.85	1	1	1		7/22:05:01.62	1	1	1	
129	COR18	Gardner, Chester S	USA	7/23:17:42.79	1	1	1		7/23:18:18.54	1	1	1	
134	COR22	Hardesty	USA	8/07:05:45.39	0	0	1	SLP9	8/07:06:23.39	0	0	0	
134	COR91	Proffitt, Mike	U.S.	8/07:05:50.60	0	0	1	SLP9	8/07:06:28.38	0	0	0	
142	COR30	Khmelevtsov, S	Russia	8/18:52:49.30	1	1	1		8/18:53:10.51	1	1	1	
144	COR67	Van Lammeren, A.	Netherlands	8/21:53:20.86	1	1	1		8/21:54:20.43	1	1	1	

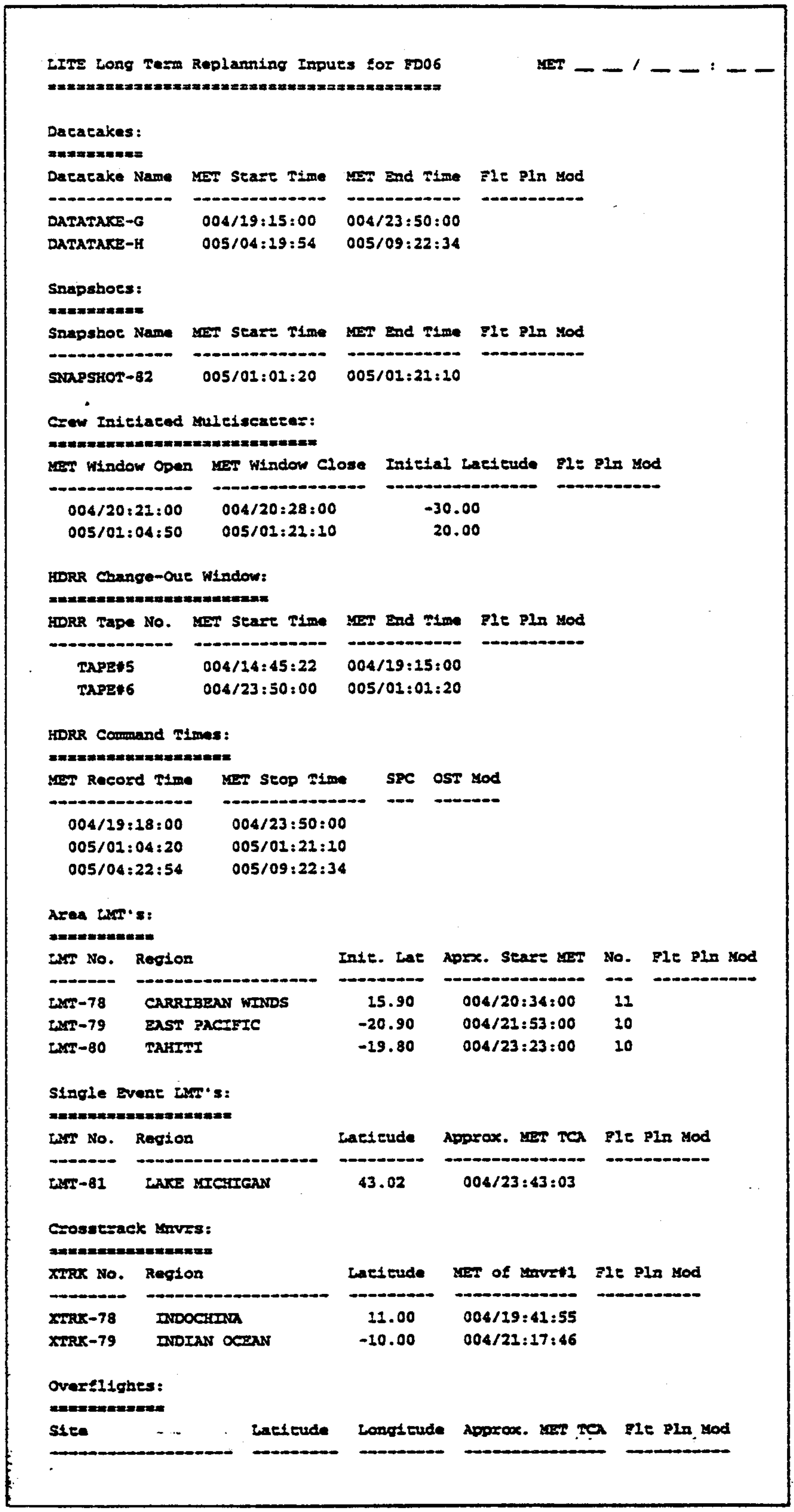
Figure 5 Correlative Sites Target Database

LITE EVENTS SCHEDULE



LAUNCH TIME: SEPT. 9, 1994 20:30 GMT / ASC LAND
DATE: SEPTEMBER 6, 1994 REV: 5.0

Figure 6 LITE Data Take Profile



```
LITE Long Term Replanning Inputs for FD06          MET __ __ / __ __ : __ __
========================================

Datatakes:
==========
Datatake Name  MET Start Time  MET End Time  Flt Pln Mod
-------------  --------------  ------------  -----------
DATATAKE-G       004/19:15:00  004/23:50:00
DATATAKE-H       005/04:19:54  005/09:22:34

Snapshots:
==========
Snapshot Name  MET Start Time  MET End Time  Flt Pln Mod
-------------  --------------  ------------  -----------
SNAPSHOT-82      005/01:01:20  005/01:21:10

Crew Initiated Multiscatter:
============================
MET Window Open  MET Window Close  Initial Latitude  Flt Pln Mod
---------------  ----------------  ----------------  -----------
  004/20:21:00     004/20:28:00          -30.00
  005/01:04:50     005/01:21:10           20.00

HDRR Change-Out Window:
=======================
HDRR Tape No.  MET Start Time  MET End Time  Flt Pln Mod
-------------  --------------  ------------  -----------
   TAPE#5        004/14:45:22  004/19:15:00
   TAPE#6        004/23:50:00  005/01:01:20

HDRR Command Times:
===================
MET Record Time   MET Stop Time    SPC  OST Mod
---------------   ---------------  ---  -------
  004/19:18:00      004/23:50:00
  005/01:04:20      005/01:21:10
  005/04:22:54      005/09:22:34

Area LMT's:
===========
LMT No.  Region               Init. Lat  Aprx. Start MET  No.  Flt Pln Mod
-------  -------------------  ---------  ---------------  ---  -----------
LMT-78    CARRIBEAN WINDS         15.90     004/20:34:00   11
LMT-79    EAST PACIFIC           -20.90     004/21:53:00   10
LMT-80    TAHITI                 -19.80     004/23:23:00   10

Single Event LMT's:
===================
LMT No.  Region               Latitude   Approx. MET TCA  Flt Pln Mod
-------  -------------------  ---------  ---------------  -----------
LMT-81    LAKE MICHIGAN          43.02      004/23:43:03

Crosstrack Mnvrs:
=================
XTRK No.  Region               Latitude   MET of Mnvr#1  Flt Pln Mod
--------  -------------------  ---------  -------------  -----------
XTRK-78    INDOCHINA              11.00     004/19:41:55
XTRK-79    INDIAN OCEAN          -10.00     004/21:17:46

Overflights:
============
Site                 Latitude   Longitude  Approx. MET TCA  Flt Pln Mod
-------------------  ---------  ---------  ---------------  -----------
```

Figure 7 Replan Form for Flight Day 06