USING VIRTUAL REALITY FOR SCIENCE MISSION PLANNING: A MARS PATHFINDER CASE

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ABSTRACT

NASA's Mars Pathfinder Project requires a Ground Data System (GDS) that supports both an engineering and a science payload with reduced mission operations staffing, and short planning schedules. Also, successful surface operation of the lander camera requires efficient mission planning and accurate pointing of the camera,

To meet these challenges, the GDS Team designed a new software strategy that integrates virtual reality technology with existing JPL Navigational Ancillary Information Facilities (NAIF) and image processing capabilities. The result is an interactive, workstation-based application software that provides a high resolution, 3-dimensional, stereo display of Mars as if it were viewed through the lander camera. The design, implementation strategy and parameter specification phases for the development of this software have already been completed, and the prototype has been tested. When completed, this software will allow science investigators and mission planners to access simulated and actual scenes of Mars' surface. The perspective from the lander camera will enable scientists to plan activities more accurately and completely, The application also will support the sequence and command generation process, and will allow testing and verification of camera-pointing commands via simulation of the sequence.

This paper describes the architecture and characteristics of this science mission planning software now under development for Mars Pathfinder, including output from the prototype. Also, it addresses possible uses of this software by other planetary missions.

INTRODUCTION

The Mars Pathfinder Project is the first of NASA's Discovery Program missions. Discovery-class means low development cost ($1 50 Million or less), short development time (3 years or less), and focused science objectives. The Mars Pathfinder mission is the first lander mission since Viking in 1976. During the Viking Mission, many of the mission operations activities were labor-intensive, costly and time consuming, especially in the area of science mission planning for the imaging system, The Pathfinder Ground Data System (GDS) Team provided the functional design for a new software that eliminates much of the labor intensive work in mission planning for the lander imaging system, Imager for Mars Pathfinder (IMP).

The resulting software, named SIMP (Simulator for IMP), creates a 'virtual Mars environment" on a workstation using high resolution, 3-dimensional, stereographic display of Mars terrain and atmosphere. This innovative use of workstation-based virtual reality enables scientists and mission operation's staff to plan the observations easily and accurately, This application supports the sequence and command generation process, as well as verification of the generated sequence.

The first prototype of the SIMP was tested recently and received favorable reviews by scientists as well as mission operations team. The prototype will go through several tests and refinement within the next 12 months. l-he SIMP can also be used for other future lander missions, such as landers in the Mars Program, with little modification.

MISSION DESCRIPTION

The Mars Pathfinder project development began in October 1993.

The spacecraft will be launched during the 1996 Mars opportunity (between December 5, 1996 and January 3, 1997), on a Delta II launch vehicle. The spacecraft will spend 6 to 7 months in cruise using a type I trajectory, and will land on Mars on July 4, 1997, The surface mission on Mars will be completed by August 1997.

The Mars Pathfinder mission's primary objective is to demonstrate the low cost engineering technology involving the cruise, entry, descent, and landing system required to place a payload on the Martian surface in an operational configuration. In addition, the lander carries a micro-rover as a technology instrument. The lander deploys the rover upon opening of the solar panels. The rover will be driven off of the solar panel after deployment of the solar panel.

The flight system consists of four main parts: 1) Aeroshell, parachute, and airbag Entry, Descent, Landing (EDL) System (See Figure 1), 2) Self righting, tetrahedral lander (See Figure 2), 3) Active thermal system for the lander (See Figure 3), and 4)Free ranging rover.

Figure 1 illustrates the EDL sequence. The spacecraft is enclosed within an aeroshell during cruise. After entering into the Martian atmosphere, a parachute is deployed to reduce the impact speed. Just before the landing, air bags are inflated to cushion the impact, and the parachute is jettisoned away from the lander position.

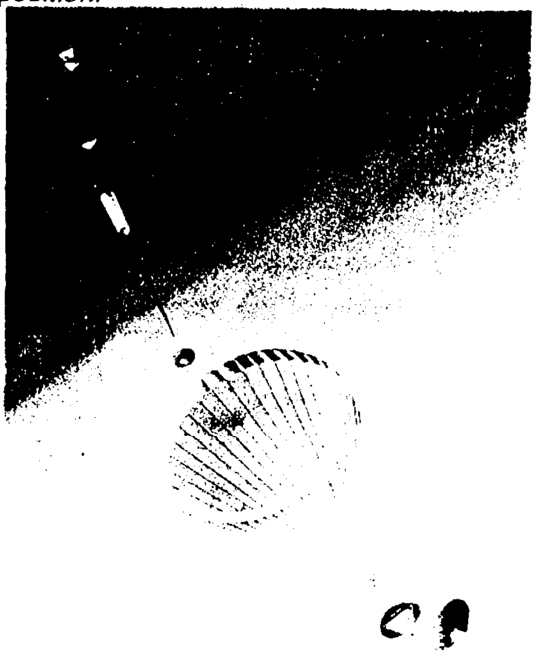

Figure 1 - *Mars Pathfinder Entry, Descent, Landing (EDL) Sequence*

The lander carries a significant science payload, There are several science instruments relating to atmospherics, meteorology, geology and imaging, Imager for Mars Pathfinder is the main science instrument, and it consists of a stereo camera with color image capability. The imaging system is located near the center of the lander and is controlled by a set of motors. Figure 3 shows the lander and its payload.

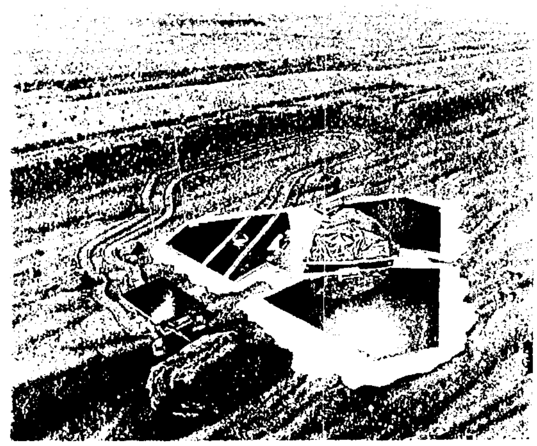

Figure 2 - *Artist's Conceptualization of the Lander on the Surface of Mars*

MISSION PLANNING FOR VIKING AN[) MARS PATHFINDER CAMERA

In order for scientists to control the camera, they need to specify approximately 32 different parameters, ranging from ephemeris information to optimum data compression ratio. The most basic parameters are displacement angle in azimuth and elevation direction (i.e. targeting parameters), and the location of the Sun.

During Viking mission operations, image mission planning was achieved by using the 'Skyline drawings', timeline, and many hours of intensive calculations of essential quantities, Although this system served its purpose well, this was a labor-intensive, time consuming and inefficient process.

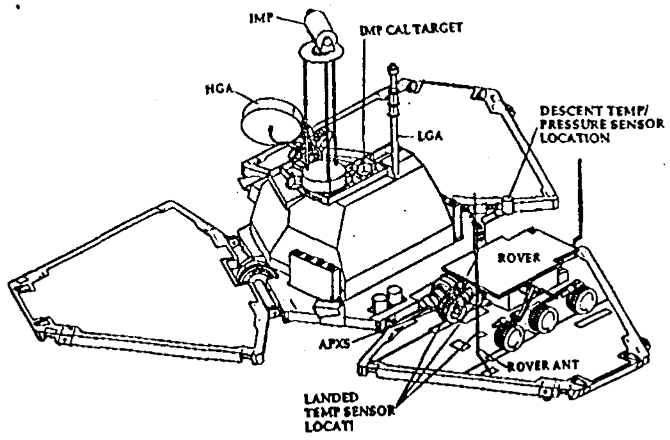

Figure 3- *Pathfinder Lander* ***Configuration***

Figure 4 shows the actual Skyline Drawings used by the Viking Lander-1, during Sol-O and Sol-1. (A 'Martian sol" is a solar day for Mars which is equivalent **to** 24.66 Earth solar hours.) **The** Skyline Drawings show image outlines on a rectilinear grid whose horizontal axis represents the azimuth and the **vertical** axis represents the elevation.

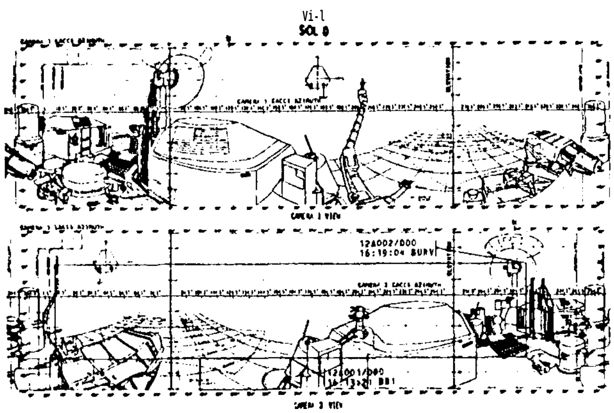

Figure 4- Skyline Drawings Used *in the Viking* ***Lander Mission***

The Viking Lander Timeline, shown in Figure 5, was also used as a main part of **mission** planning. This **timeline** shows the Viking Lander-1's **mission** activities during Sol 22. As one can see, these resources are unsuitable to use for new missions like Mars Pathfinder, considering advanced technology that is available today.

The proposal for the image mission planning tool for the Pathfinder was to create a 'virtual Mars' environment, The idea is to simulate the camera using a workstation such as Silicon Graphics or Sun. The simulator creates a virtual Mars environment on a workstation screen, displaying 3-dimensional, stereographic images of Mars' terrain as well as its atmosphere. The **scene** created should look as if it were seen by the camera. This idea utilizes existing hardware and entails only a small cost. The **scenes** of Mars will be viewed with stereo viewing devices already widely available.

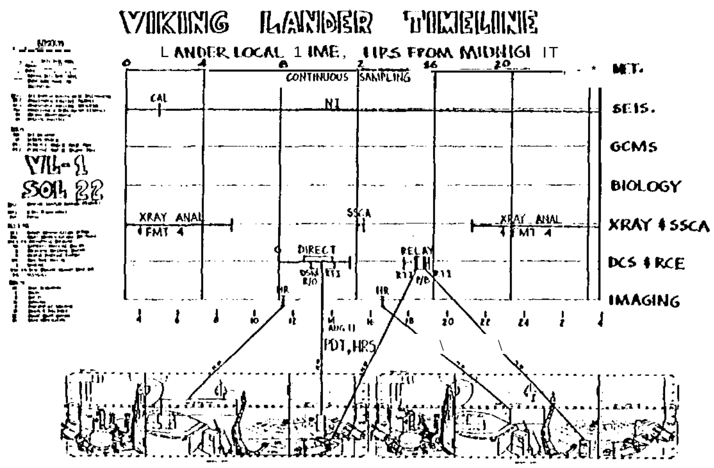

Figure 5- *Viking Lander* ***Timeline***

DESIGN OF **SIMP**

The SIMP design approach was different from the traditional approach at JPL. The decision was made to start the design without a detailed functional requirement document or schedule. Instead, this software development relied on close interaction between team members. This approach allows all team members to understand the purpose of the task, and the significance of **their** roles toward accomplishing the task. Most importantly, each member is completely responsible for his contribution to this task, but at the same time, to work as a cooperative team member,

The design phase of development began with a meeting between representatives of the Ground Systems, Image Processing, Science, and SIMP implementation team. During this initial meeting, the purpose and functions were identified, and concepts for creating a virtual Mars were proposed. In addition, the description of the mission, launch schedule and mission operations plan were discussed. The design team agreed that providing a comprehensive user's guide and a software description would be the only necessary documentation. The design team also decided that incorporating NAIF/SPICE is an appropriate approach to get ancillary information. (The description of NAIF/SPICE is attached as Appendix A,)

After a few months, the initial prototype was completed. The design team presented the prototype to scientists for a review, and found the prototype to be satisfactory in terms of meeting a foreseen necessary functions for mission planning, At this point, the implementation team decided to proceed with detailed development' of SIMP, including some additional requested functionality. Figure 6 shows the prototype of SIMP.

SIMP creates a virtual Mars environment by displaying either single or mosaic images, in stereo view. There is an option to display either the Mars local coordinate reference or lander center coordinate reference on the border of the scene. Graphical display of azimuth and elevation angle, field of view and field of regard (ranges within the camera can move) are placed below the scene. In addition, there are text display of other parameters such filter and exposure information. On the scene, motor step grid and field of view are overlaid for quick reference,

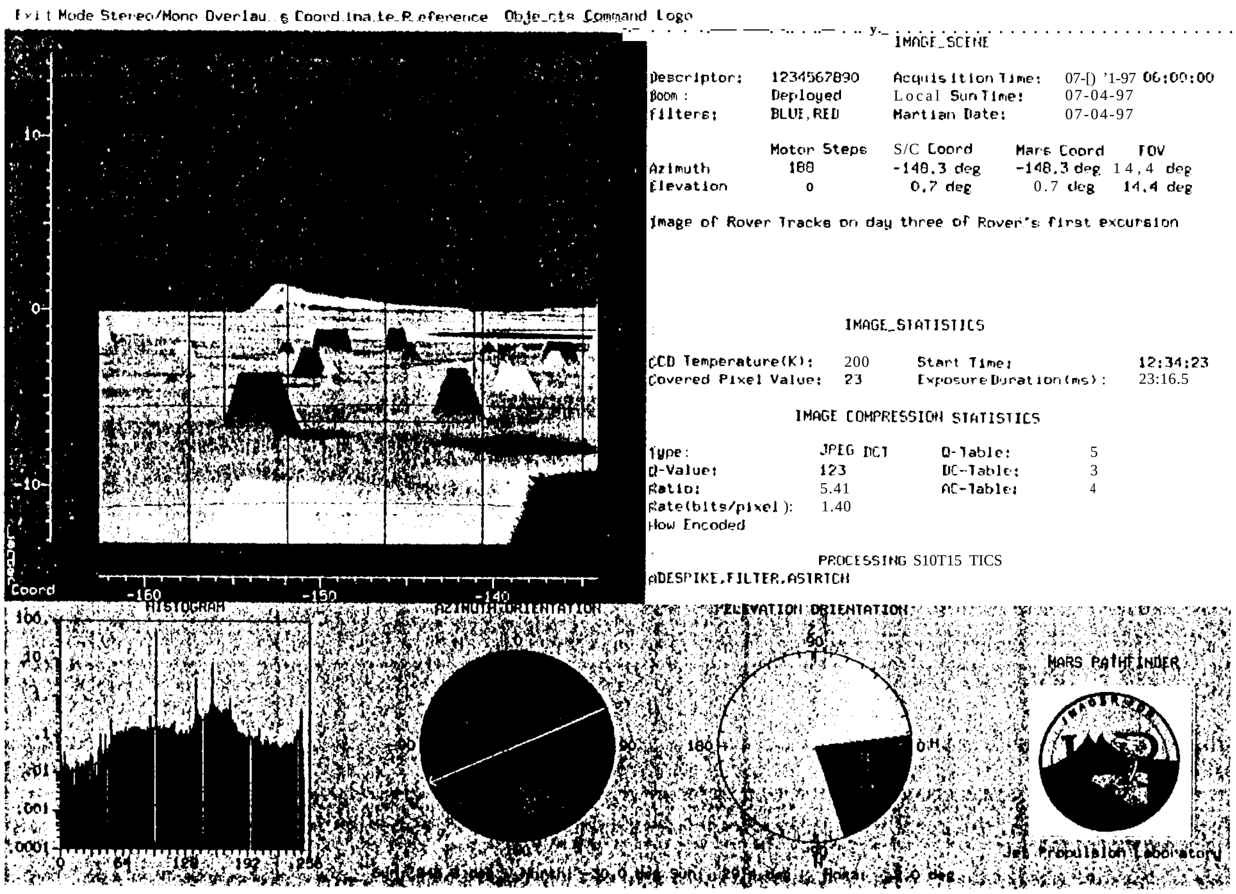

Figure 6- *Display from **SIMP** Prototype*

PLAN FOR TESTING AND REFINEMENT

It is our plan to refine SIMP through continuous communication between GDS, the implementation team and the science team. Also, SIMP is schedule to be connected to the camera engineering model to test the real-time interface and its accuracy.

Within the next month, the design team of SIMP will participate in a special test activity, **in cooperation with the science team,** The Principal Investigator of the camera at the University of Arizona will create a pseudo-Mars, named Mars Garden, by designing an area according to available Mars data. The engineering model of IMP will be mounted within the Mars Garden and will be connected to a control system. At that time, SIMP will be connected to the control system to simulate the mission operations environment, This test will give us useful accuracy data as well as usability information about SIMP.

Figure 7 is a conceptual model of Mars Pathfinder's uplink (command) system. SEQGEN and SEQTRAN are sequence processing software currently used at JPL. SASF and SSF are input files for SEQGEN and SEQTRAN. As shown, SIMP will provide planning function as well as validation of the designed sequence. During next phase of Mars Pathfinder's system testing, SIMP will be placed within the uplink system to-be integrated with the rest of the GDS

POTENTIAL **USE BY FUTURE LANDER MISS1ON**

Currently, there is a proposed plan to repeatedly launch landers as Mars to conduct various scientific investigations. SIMP can be used to simulate any camera or remote sensing instrument on any of the future landers, with little modification. The only foreseeable modification required will be to generate SPICE kernel files for spacecraft and the camera, SIMP is independent of landing location or mission dates,

SUMMARY

Through design and development of SIMP, the Mars Pathfinder GDS has shown that an innovative use of virtual reality concept produced a high quality, re-usable tool for science mission planning. The resulting tool will accommodate scientists with accurate information when planning or validating their mission sequence. Furthermore, this tool can be used for any future landers regardless of time or the destination of the mission.

Note:
The SIMP tool development is part of the Model Based Planetary Tools Analysis Task funded by Joe Bredenkamp of Code ST, NASA. This effort described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology under contract with NASA.

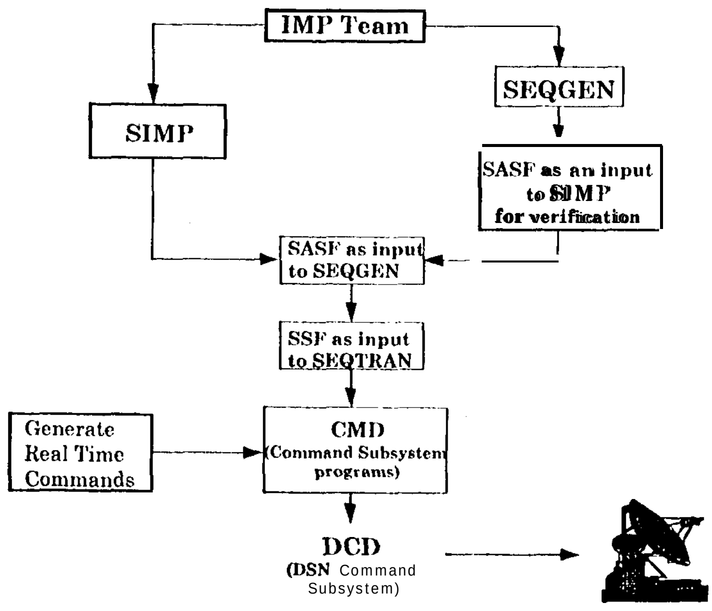

Figure 7- *IMP Uplink Process (Conceptual Model)*

APPENDIX A

"Kernel Knowledge"
NAIF/SPICE Description, published by NAIF Group at JPL. (attached)

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Kernel

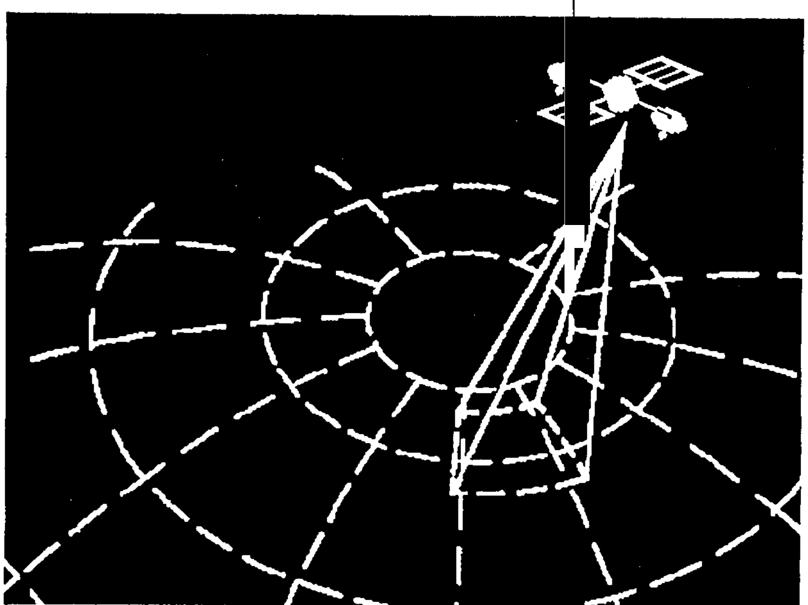
Know/edge

Navigation

Ancillary

Information

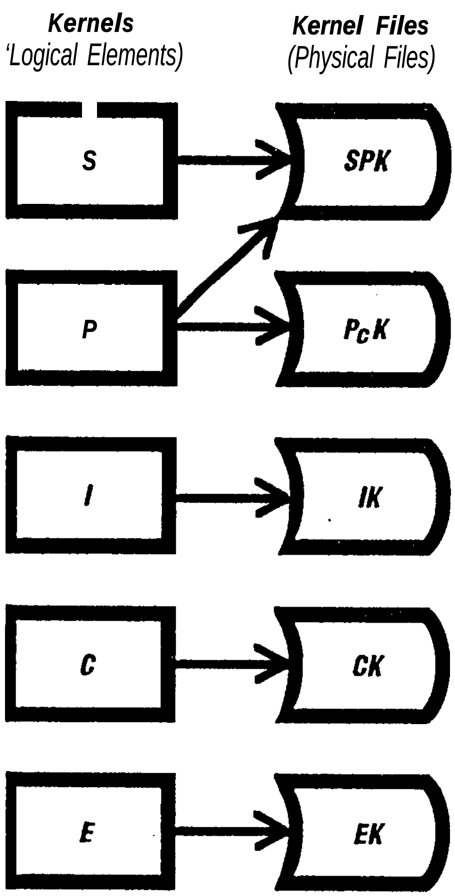
Facility



Mapping SPICE Kernels Into Real Products

Historically, the ancillary data needed to support the planning and analysis of observations made by instruments on spacecraft have been organized into five logical elements—called *kernels*—as shown in the left half of the figure, and as described in the table. The acronym SPICE was coined to refer to these kernels.

Kernel	Contents	Description
S	Spacecraft ephemeris	Position and velocity of a spacecraft as a function of time.
P	Planet ephemeris and constants	Position and velocity of a planet, satellite, comet, asteroid, or the Sun as a function of time. Also, cartographic constants for that object.
I	Instrument descriptions	Instrument mounting alignment, internal timing, and other information needed to interpret measurements made with an installment.
C	Camera pointing	The inertially referenced attitude (pointing) for an instrument or other spacecraft structure as a function of time.
E	Events	Spacecraft and instrument commands, ground data system event logs, and experimenter's "notebook" records.



Kernel data are distributed in five kinds of files, called **kernel files,** as listed in the table (right,)

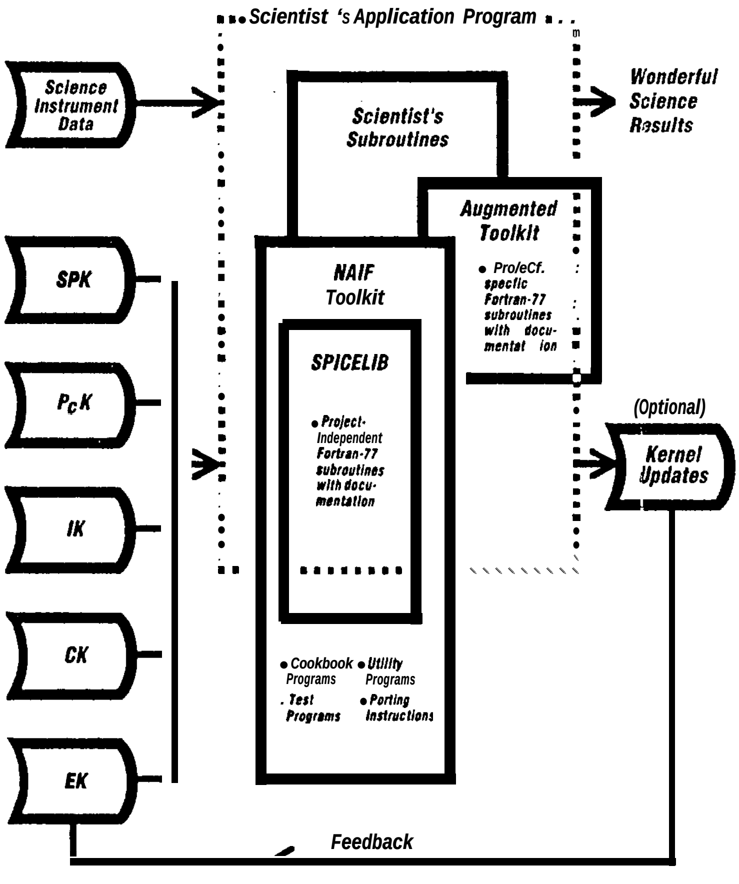
File	Format	Description
SPK	Binary	Data from the S kernel, or from the ephemeris portion ($P_{ephemeris}$) of tha P kernel, or both.
P_cK	Text	Data from the constants portion ($P_{constants}$) of the P kernel.
IK	Text	Data from the i kernel.
CK	Binary	Data from the C kernel.
EK	Text	Data from the E kernel.

Data from the S and the $P_{ephemeris}$ kernels are generally used together (the state of a spacecraft is normally defined with respect to a planetary object); and may be included in a single file.

Most kernel files are originally produced by a flight project, such as Magellan, Galileo, or Mars Observer. Updates to these files could be produced both by the project and by planetary scientists during the course of their analyses.

In addition, NAIF produces some SPK kernel files containing planet, satellite, comet, asteroid, and Sun ephemerides for general use, These kernel files are derived from reference ephemerides provided by the Jet Propulsion Laboratory's Navigation Systems Section.

Using the SPICE System



SPICE Helps **Interpret** Science Instrument Data

The elements of the SPICE system-kernel files and software-are used to support the planning and analysis of space science data.

A scientist's application program might use pictures from the Mars Observer Camera to help determine the suitability of a particular region as a landing site for a sample return mission. The primary scientific result would be estimates of parameters that define local topography. A secondary result could be improved estimates of precisely where the camera was pointed when the pictures were taken; these data could be placed in a new C-kernel file.

SPICELIB—the principal SPICE software-is a collection of subroutines written in ANSI Fortran-77. Some of these subroutines read, write, and port binary kernel files, and read text kernel files. (Binary files are converted to an inter. mediate text format for transfer between various computers.]

The remaining subroutines use the information contained in those files to compute the geometric quantities {vectors, angles, distances) needed to plan observations or to interpret the data returned from science instruments. Each subroutine includes the information needed to select and properly integrate the subroutine into the scientist's own application programs.

The NAIF Toolkit consists of SPICELIB source code, including documentation, plus the following additional items:

Cookbook **Programs are** highly annotated, working programs that illustrate how SPICE kernels and SPICELIB subroutines may be used to compute commonly requested geometric quantities (Sample kernel files are included.)

Test Programs can be executed by a Toolkit recipient to verify that the Toolkit code has been successfully ported to the recipient's own computer.

Utility Programs fall into two categories. Some can be used to examine and convert binary kernel files; others can be used to gain easy access to descriptions of SPICELIB subroutines.

Porting Instructions identify changes that nee to be made when the Toolkit is moved between various computers.

SPICE **Offers** Wide Applicability

The NAIF Toolkit can be used in planetary, space physics, and Earth scienc applications. It maybe augmented with project-specific subroutines as needed, with NAIF normally providing this code under project funding.

Scientists or engineers pick needed Toolkit subroutines and combine them with their own software to create an application program, (Toolkit users should *not* revise Toolkit subroutines.)

When used in support of NASA flight project, SPICE kernel files and Toolkit software (including augmentations), are archived with science instrument datasets for future reference,

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What is SPICE?

SPICE is a NASA **information system for assem-bling,** archiving, distributing, and accessing geometric and related ancillary information used to plan space science observations and interpret space science instrument date. This brochure describes the content and use of the basic SPICE system components.

The SPICE concept was defined by planetary scientists, and is being implemented by the staff of the Navigation Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory, with oversight by the science community,

Funding for development of the SPICE system is provided by the Information Systems Branch and the Solar System Exploration Division of NASA 's Office of Space Science and Applications,