WEIGHTLESS IN outer space, astronaut Sally Ride and three HP 41s float freely on the flight deck of the space shuttle Challenger.

HP 41

When communication between the orbiting space shuttle and the ground fails, only the HP 41 stands between a safe re-entry and disaster.

The orbiting space shuttle is in trouble. Communications with the ground are out and the power systems are failing. Soon there won't be enough power for a controlled re-entry. It's time to come home.

The astronauts face a key decision—when to fire the retro rockets. The orbital maneuvering engines must be fired at precisely the right time for the shuttle to reach one of the designated landing sites or it will crash-land or ditch in the ocean.

As the astronauts learn early in their training, the on-board computers are not programmed to calculate deorbit opportunities. Without this critical information from ground controllers, the situation looks hopeless.

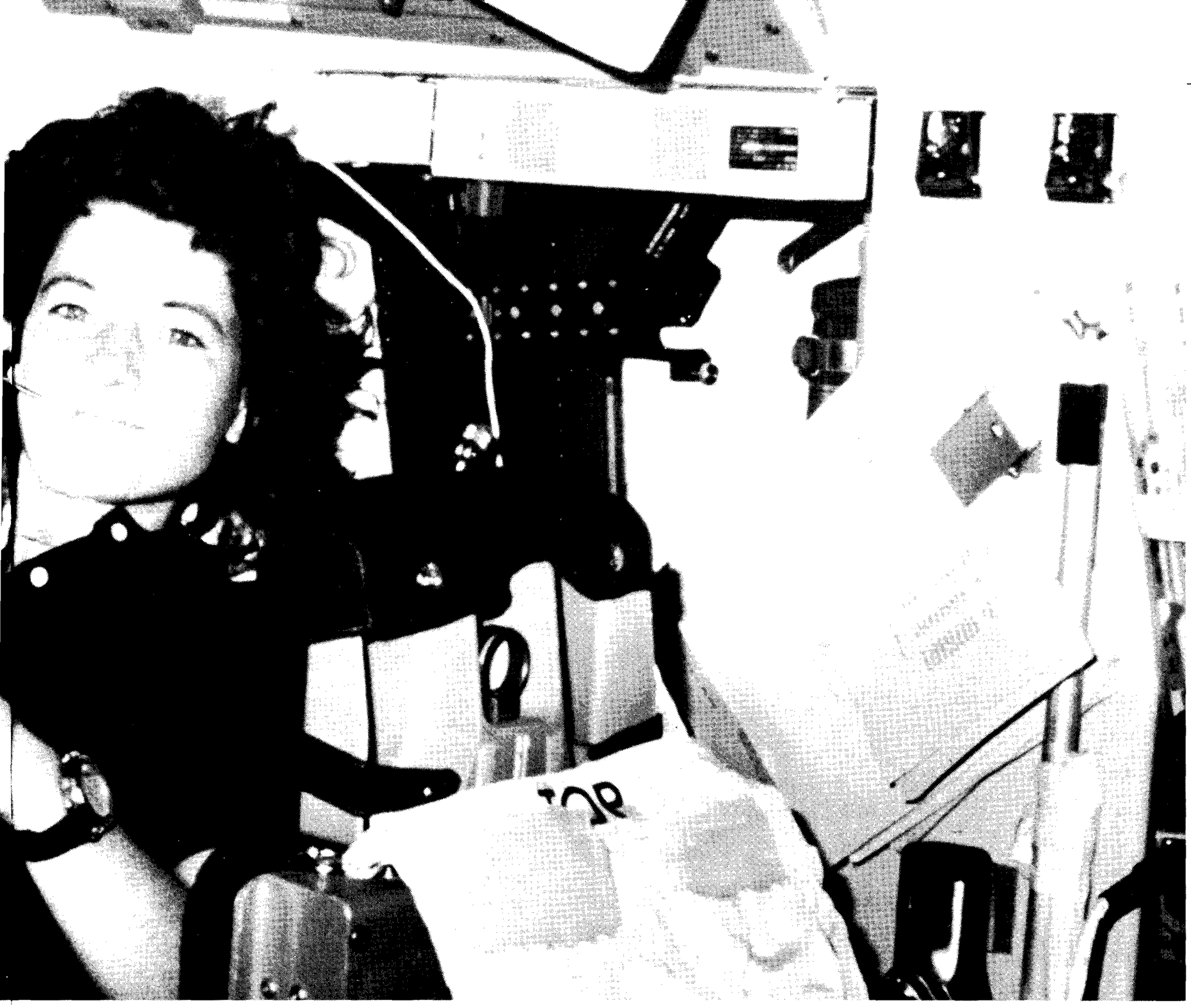
Mission commander Bob Crippen turns to mission specialist Terry Hart with a grin and says, "Go for it, Terry!"

Stuck to a nearby console is a rather fuzzy-looking HP 41, one of several on board. Close inspection reveals that practically every unused surface of the calculator is covered with Velcro, so that in the zero gravity of space it can easily be stuck to any handy surface.

Hart reaches for the 41 and presses a key labeled DEO on the keyboard overlay. The message DEORB READY appears on the display. Hart then presses the NEXT key and DEORB SEARCH is displayed. A series of tones is heard and the display shows

DKR 0.223402

indicating that Dakar, Senegal, is the next landing opportunity and ignition for the deorbit burn will be at 0 days, 22 hours, 34 minutes and 2 seconds mission elapsed



IN ORBIT

BY KEITH JARETT

time—only two minutes away.

As Crippen gets set to fire the engines, Hart presses the R/S (Run/Stop) key and finds out that Dakar is 480 nautical miles north of the shuttle's ground track, well within its glide capabilities.

Once the rockets have been fired, the on-board computers navigate the shuttle to the landing area. The astronauts step out. Another successful mission simulation, thanks to the HP 41.

Emergency situations like this are practiced frequently in flight simulators. Although the 41 has never been needed to compute a deorbit opportunity in flight, it's carried, programmed and ready, on each mission.

WHY THE HP 41

Six months before the first shuttle flight, Terry Hart was asked to find the best calculator for the astronauts. He looked at the TI-59 and the HP 41, the most powerful units available, and decided that the 41's alphanumeric display capability made it the clear winner.

Once he decided on the 41, Hart realized he had more than just the handheld scientific calculator NASA had wanted. He started to look for more complex jobs to use it for. The deorbit program is one example. Computation of a deorbit opportunity would have been easy for the on-board computers, but the software for it never was developed.

Since the 41s would already be on board as general-purpose calculators, Hart began to develop additional programs for them. Assisting in program development were Steve Hoefer of McDonnell-Douglas and NASA's Terry Stanford, who also handled the flight

PHOTO COURTESY OF NASA

Programs developed for the on-board 41s compute the shuttle's center of gravity, its ground track and ignition times for re-entry.

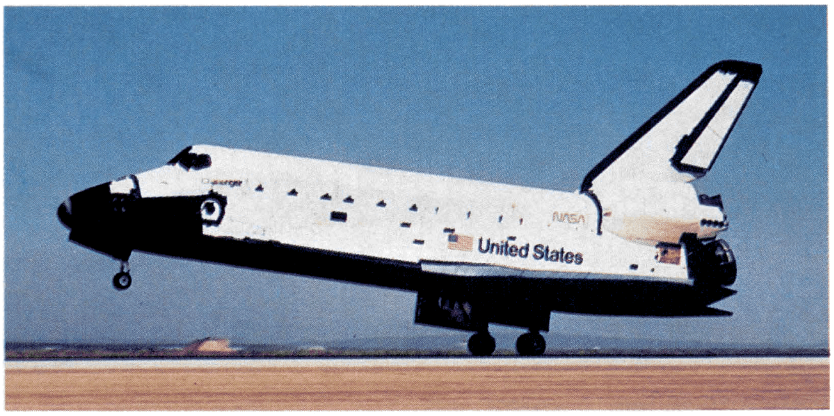
certification of the calculators and programs.

Dave Lamar of NASA is now responsible for 41 program development. Under his direction, new programs are being added for specific mission applications and revisions will probably be made as long as the 41s continue to fly.

SHUTTLE PROGRAMS

CG, the first 41 shuttle program, computes the center of gravity of the orbiter as fuel from the tanks is consumed. Knowing where the orbiter's center of gravity is allows for more efficient orbital maneuvering.

Another program, *Landtrack*, computes the ground track of the shuttle, identifying points of interest on the earth's surface for observation. These two programs were on board the first two shuttle flights.



CHALLENGER LANDING **at Edwards Air Force Base.**

The most widely used 41 shuttle program is *Deorbit/Alarm/AOS*, consisting of three separate sections. *Deorbit*, described earlier, allows the astronauts to compute ignition times for re-entry. *Alarm* provides a convenient way to use the alarm capabilities of the time module, a plug-in for the 41 with an accurate, fully programmable, quartz clock and stopwatch. One function allows alarms to be set relative to the actual time. Another sets alarms in mission-elapsed time and is suitable for deployment sequences or other events fixed relative to launch time. Each alarm can be accompanied by a reminder display selected by the astronaut. Alarms for deployment or other mission sequences can be loaded from magnetic cards or from a cassette drive.

Acquisition of Signal (AOS), which runs continuously throughout the mission, is important because there is direct communication with ground controllers only during passes over one of 13 earth stations. These passes last about 10 minutes, less if the shuttle does not pass directly over the earth station.

AOS beeps at the start of a pass over an earth station and displays the time remaining to loss of signal (LOS). This helps the astronauts make the best use of the short periods of communication available. The program shows the name of the station being passed and whether UHF, S-band (2250 MHz microwave) or both frequencies are available. For example, the display AOS HAWB 7 indicates acquisition of signal from Hawaii, both communication frequencies available and LOS will occur in seven minutes. Each minute, the display counts down to loss of signal.

When LOS is reached, the program uses its knowledge of the shuttle's orbital parameters to predict when the next pass will start. The program also calculates the duration of the pass and the identity of the ground station. This information is used to construct a time module alarm. The program then halts, remaining dormant until the beginning of the next pass. An alarm then wakes up the 41 and starts the countdown to the next LOS.

The key feature of the AOS/LOS program is the interrupting control alarm function of the time module. When the alarm time is reached, the calculator begins to execute the specified program—in this case, displaying the message and counting down to LOS.

Computing AOS and LOS times and then using alarms to control when the messages are displayed overcomes the speed limitations of the 41. Since constant computation is not required, the calculation can be performed at leisure.

The first shuttle flights were made before the time module for the 41 was released. NASA was allowed to use an early version of the module in what has to be the ultimate in pre-production testing. That may be why the time module is one of the most powerful, bug-free and well-documented modules for the 41 ever released. Credit for that goes to Dennis York of HP Corvallis and Martin Richardson, a local HP representative, who supported Terry

NASA TECHNICIAN **demonstrates in-flight use of the HP-41 in the shuttle simulator.**

Hart and the rest of the NASA team by providing the prototype module and software still in the debugging stage.

FEATURES OF THE 41

For several reasons, the 41 was the right machine for NASA. In 1981 it was the most powerful handheld available. It still is, for its size and weight. Some handhelds, including the HP 71, match the 41's computing power in a slightly heavier package. But none of them can match the 41's convenience as a scientific calculator. Furthermore, only the 41 and HP Series 70 machines have the extensive time and alarm features needed by NASA for applications such as acquisition of signal.

Complete keyboard redefinition, introduced with the 41, is important for NASA. There isn't enough time in the training program to teach all the astronauts how to program a 41. The User mode, in which each key activates a program or portion of a program, simplifies the training task because the astronauts only have to be familiar with what the programs do. A keyboard overlay clearly shows the function of each key.

The high degree of customization possible in User mode makes the 41 ideal for use by non-programmers with limited training. This doesn't make the job of the programmers easier, but NASA engineers have come up with a set of programs (*CG*, *Landtrack* and *Deorbit/Alarm/AOS*) that are easy to use.

NASA originally chose the 41 for routine calculations—it certainly is a fine scientific calculator. In reality, the 41s on the space shuttle are hardly ever used simply as nonprogrammable calculators. Most of the time they sit on a console or are stuck to the astronauts' suits and are running the *AOS* or other programs.

In asking for a scientific calculator and getting the 41, NASA ended up with more than it bargained for.

The 41 has other advantages. It's easy to program and virtually impossible to crash because of the high quality of its internal programming.

Because the 41 is battery-powered, it's independent of the shuttle's power systems and can be taken all over the cabin.

NASA can equip each mission with several 41s because they weigh less than seven ounces with batteries. Given the shuttle's tight weight limitations, the 41 is the nearest

SPECIFICATIONS

HP 41CV:
- 320 registers (2240 bytes) of memory
- Four-register stack plus 24-character ALPHA register
- 12-position alphanumeric display
- fully redefinable keyboard with 35 keys
- more than 100 built-in functions (trig, log, arithmetic, statistical, etc.)
- four ports for plug-in modules (preprogrammed modules, extra memory, card reader, etc.)

Extended functions/memory module:
- 47 additional functions including programmable SIZE (data/program register allocation)
- 127 registers of extended memory for off-line storage of programs and data

Extended memory module:
- 238 registers of extended memory for off-line storage of programs and data
- requires extended functions

Time module:
- internal quartz clock and stopwatch
- adjustable accuracy factor to compensate for frequency drift
- 29 time-related functions (stopwatch, alarm, etc.)

PHOTOS COURTESY OF HEWLETT-PACKARD

The 41s NASA uses are not specially prepared. They're the same machines you get at your local store.

thing to free computing power.

HARDWARE

Each shuttle flight normally carries one HP 41 per crew member. Two 41s can be loaded with one set of programs, and two with another set for additional backup. A card reader and a cassette tape drive are available in case the programs need to be reloaded.

Each 41 is equipped with a time module, an extended functions module, and two extended memory modules. If a card reader is needed, one of the extended memory modules is removed. The extended memory modules allow the total program capacity of the 41 to be doubled (one additional module) or tripled (two additional modules). Programs are stored in extended memory, then brought into main memory when needed for execution.

One special piece of 41 hardware was developed for NASA because the inside of a space shuttle is not as quiet as you might imagine. Cooling fans and other equipment can mask the relatively subdued tones of the 41's built-in beeper, so a louder beeper was needed.

Hart, with HP's cooperation, found the answer. A one-inch speaker was fitted inside an empty card reader case. A simple two-transistor amplifier was added to drive the speaker. The 41's port 4 connector was modified to provide the beeper drive signal on two of the pins, creating the loudest HP-41 ever heard.

This custom accessory aside, the 41s NASA uses are not special models. They're the same models you get at your local store. The only modification NASA makes is sticking Velcro strips all over the case so that the astronauts can attach the calculators to their flight suits. Non-skid feet are not much good in space.

The machine that pioneered alphanumeric display, keyboard customization and other advanced features continues to pioneer in space. If you're one of the million or more HP 41 owners, you're in good company. □

Keith Jarett is a satellite systems engineer and an HP 41 addict. He is the author of two books on synthetic programming.

SHUTTLE RADAR RENDEZVOUS PROGRAM

This program was used on Mission 41-C, the Solar Max repair mission, and on the preceding flight, STS-10, which tested the shuttle's radar-guided rendezvous capability. The program uses the time module's stopwatch functions to provide a quick estimate of the closing rate to a satellite being approached.

Astronauts periodically key in the current target range (in feet) and press an assigned key to execute the RDOT program (r-dot is the time-derivative of the range r). The program then estimates the closing rate, based on the last two range entries and the time they were entered. For example, the display

9543. −204.1

indicates a range of 9543 feet and a range rate of 204.1 feet per second (closing). The negative sign means that the range is decreasing.

If the astronaut presses R/S without entering a current range value, the LBL 01 (Label 1) portion of the program estimates the current range based on the last two entries. The estimate will be reasonably accurate if no thrusters have been fired since the first of the last two range entries was made.

```
01♦LBL "RDOT"
 02 DEG
 03 STO 01
 04 STOPSW
 05 RCLSW
 06 STO 02
 07 0
 08 SETSW
 09 RUNSW
 10 FC? 15
 11 GTO 00
 12 RCL 02
 13 FRC
 14 100
 15 *
 16 ENTER↑
 17 INT
 18 60
 19 *
 20 X<>Y
 21 FRC
 22 100
 23 *
 24 +
 25 STO 02
 26 RCL 01
 27 RCL 00
 28 -
 29 RCL 02
 30 /
 31 STO 02

32♦LBL 00
 33 CLA
 34 FIX 0
 35 ARCL 01
 36 FC? 15
 37 GTO 00
 38 "├ "
 39 FIX 1
 40 ARCL 02

41♦LBL 00
 42 RCL 01
 43 STO 00
 44 SF 15
 45 PROMPT

46♦LBL 01
 47 RCLSW
 48 FRC
 49 100
 50 *
 51 ENTER↑
 52 INT
 53 60
 54 *
 55 X<>Y
 56 FRC
 57 100
 58 *
 59 +
 60 RCL 02
 61 *
 62 RCL 01
 63 +
 64 CLA
 65 FIX 0
 66 ARCL X
 67 "├ "
 68 FIX 1
 69 ARCL 02
 70 PROMPT
 71 GTO 01
 72 END
```