

## THE UNIVERSITY OF WISCONSIN

### OAO OPERATING SYSTEM

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#### I. INTRODUCTION

In a volume dealing with the results and accomplishments of the Orbiting Astronomical Observatory OAO-2, it seems appropriate to consider also the problems connected with operating the spacecraft. This paper presents the Wisconsin OAO Operating System which consists of two parts: a computer program called HARUSPEX, which makes possible reasonably efficient and convenient operation of the Wisconsin Experiment Package (WEP) and the Wisconsin Ground Operations Equipment (GOE) which provides real-time status monitoring, commanding and a "quick-look" at the data.

#### II. THE CONTROL PROBLEM

OAO-2 is essentially a 24-hour-a-day observatory requiring considerable effort if it is to be used to the full extent of its capabilities. In the course of a single day's operation, WEP may observe as many as 20 targets (stars and sky background) though normally the number would be closer to 10. Each of these targets may require five to ten separate observing commands for a complete observation.

In addition to the obvious problems of choosing interesting objects for viewing, the astronomer must contend with certain restrictions. Observations must be scheduled so that they do not interfere with ground contacts. The high level of background illumination during the time when the spacecraft is in direct sunlight makes it desirable to avoid observing during these periods. The effects of the South Atlantic radiation anomaly are even more pronounced. Data taken in the anomaly are unusable and observations must not be scheduled at that time. There are physical restrictions on spacecraft motions and pointing. In moving from one target to another, no single slew may be longer than 30 degrees. Also, large slews take a

correspondingly longer time, which must be taken into account in the observing schedule. To protect the experiment optics, the spacecraft may not point within 45 degrees of the sun or anti-sun, even during a slew. Finally, targets must be chosen so that the solar paddles may be oriented to ensure adequate power input.

In view of the problems mentioned above, it is clear that spacecraft operation is a formidable task under the best of conditions. Of course, spacecraft degradation, particularly in the control and stability systems, makes the problem even more difficult. In order to cope with the task, some computer help is necessary. For this reason, HARUSPEX was written.

### III. THE PROGRAM

HARUSPEX is a large, complex computer program intended for use by personnel who are not primarily computer-oriented. The emphasis throughout is on ease, simplicity and convenience of use. To this end, inputs to HARUSPEX are usually free-field, except where external considerations dictate use of a specific format for the input cards. Further, many of the parameters used in HARUSPEX and its subroutines can be assigned standard values. These parameters need to be entered into the program only when the user wishes to assign non-standard values. Also, many of the inputs, such as a request for punched output, are optional and need be entered only when desired. Finally, the sequence of input cards for a particular task is usually rather arbitrary. This approach has greatly reduced the frequency of trivial deck-structure and format errors.

On the output side, heavy use has been made of graphic output, in the form of printer plots rather than printed tables. Such plots, while of limited accuracy, are easier to read and interpret. Since the Support Computer Programming System (SCPS), to which the proposed WEP observing list is submitted, does very precise checking, any lack of accuracy due to the coarseness of a printer plot is not of great importance.

HARUSPEX resembles a very simple computer monitor system. The mainline program plays the part of the executive while major tasks are accomplished by means of large subroutines which are used in much the same way that a person might execute a FORTRAN compiler. In addition, HARUSPEX contains an extensive library of routines for "housekeeping," trigonometric manipulations, and other utility functions.

### IV. THE SUBROUTINES

To give some idea of the large range of tasks which must be handled by HARUSPEX, a list of those subroutines which are most frequently used is given below, with a brief description

of each.

SORT allows the astronomer to search a catalog of more than 10,000 stars, selecting those entries which meet a given combination of user-specified criteria. Possible search criteria include the star's position in celestial coordinates, its position with respect to the sun, and various properties of the star, such as magnitude and spectral type. Stars meeting the given criteria may be printed out, punched on cards, written in a disk file, or any combination of these output modes. Typically, the astronomer uses SORT to narrow down the field and makes his final target selections by hand.

Subroutine MAP is used as an aid in scheduling observations. Given a list of stars, MAP produces a time based printer plot showing the following conditions:

- (1) time and duration of ground contacts,
- (2) time and duration of spacecraft night,
- (3) time and duration of passage through the South Atlantic anomaly,
- (4) period of time when each star is visible to the spacecraft, along with indications of whether the bore-sighted star tracker may be used, and whether the line of sight to the star intersects the sunny or dark earth when the star is occulted.

Plots begin at ETA for ground contacts at Rosman, Quito or Santiago and extend for 120 minutes. The user specifies the first contact to be plotted and the number of plots desired. An example of MAP output is given in the appendix.

Subroutine BLOTS is designed to aid the astronomer in choosing available areas of the sky for observing. It produces printer plots of the sky showing those areas which are occulted by the sun, moon, anti-sun and earth. The occulted areas are plotted as blocked-in regions, each with a different symbol. BLOTS also shows the areas at the poles of the orbit which are never occulted by the earth. Finally, the star tracker guide stars are plotted, each one denoted by the number assigned to it by SCPS.

In BLOTS, the user may specify the angular radii of the occulting objects, if desired. The time of the first plot, the time interval between plots, and the number of plots to be generated are also user-specified. An example of BLOTS output is given in the appendix.

Subroutine SLEW allows the user to evaluate proposed sequences of objects to be observed. Given a list of objects, SLEW takes them pairwise (i.e. the first and second, second and third, etc.) and computes the possible sequences of motions which will move the spacecraft from one to the other. Each sequence is checked to see that it does not approach too near the sun or anti-sun. The legal sequence, if any, with the shortest

total distance slewed is chosen and printed out.

At the destination, i.e. the second position of each pair, SLEW prints out the positions of the ends of the spectrometer slits, to aid in avoiding contamination of scans due to unwanted stars in the field of view. It also gives the spacecraft's orientation with respect to the sun, which gives the astronomer information concerning the power input to the solar arrays. At both origin and destination SLEW assumes that the spacecraft's orientation is optimum for power input.

Subroutine SATAN produces a latitude-longitude plot showing the position of the sub-satellite point as a function of time. The plot also gives the locations of the South Atlantic anomaly and the ground stations. SATAN plots up to five orbits per page. Each orbit begins at the ascending node. Points are plotted at user-specified time intervals from the node crossing. Digits are plotted for the daylight portions of the orbits and 'N' for the night portions. An example of SATAN output is given in the appendix.

Subroutine TRACK is used to give the astronomer information about the availability of tracker guide stars for a proposed orientation of the spacecraft. The output can be obtained as a printer plot or as a table. In the plot mode, an example of which is shown in the appendix, TRACK produces a plot of the sky showing the limits of the available field for each star tracker, plus the positions of the OAO guide stars. In print mode TRACK produces a table giving the zenith position of each tracker, the guide stars available to it, the rise and set times of each star, and the gimbal angles necessary to set the tracker on each star.

In addition to the astronomical routines, HARUSPEX contains several file-manipulating routines. These subroutines enable the user to build, sort, merge, edit and concatenate card-image disk files. Input from cards is also permitted in these operations. The presence of these routines makes it possible for the astronomer to create and modify observing programs without the handling of large card decks, thus greatly decreasing the probability of error. The disk files so constructed can, for example, be used as input to SORT, MAP, SLEW and TRACK, as well as to the subroutine which translates the observing program into binary codes and writes the tape which is submitted to the SCPS.

## V. USING HARUSPEX

The fundamental task of HARUSPEX is the creation of the experimenters' target list (ETL), the proposed observation schedule. This is written on magnetic tape by subroutine TWERP and submitted to the SCPS for final checking. Since SCPS testing is much more detailed and extensive than that

afforded by HARUSPEX, the proposed ETL may be rejected, necessitating correction and re-processing. However, the basic sequence of events in HARUSPEX is quite simple.

The first step is to use MAP, SLEW and BLOTS to determine general sky conditions for a full week. This gives the astronomer some idea of which areas of the sky will be available (i.e. stable, unocculted, good power input, etc.) during the week. SORT gives a large list of stars located in these areas.

In the second step, the astronomer decides which stars should be observed and the sequence in which they will be viewed. The file-manipulating routines are then used to place these stars and appropriate command sequences in a data file. Commands are usually taken from a file of standard sequences, depending upon the magnitude and spectral type of the star. Non-standard commands can be entered from cards. MAP is then used to determine specific times for the various motions and command sequences. These are entered in the schedule using the file-handling routines. SLEW and TRACK are then run to check for gross violations of spacecraft constraints.

In the final phase, any re-ordering, time changes, etc., indicated by the MAP, SLEW and TRACK runs are made. Finally, TWERP is used to write the proposed ETL, which is then submitted to the SCPS.

## VI. THE MONITOR REQUIREMENT

The results of the command and control system (HARUSPEX) will be reflected in the spacecraft motions and data collected. Status having to do with the spacecraft itself is monitored by the main control center equipment while experiment data is handled by the experimenters' equipment. It is necessary to know that all requested commands were executed properly since correct observatory operation builds on the past sequence of events. It is also desirable that the astronomer have a quick look at his data since it may influence his future planning.

## VII. THE SYSTEM

In order to satisfy these requirements, the Wisconsin GOE was constructed. The heart of the system is a small computer, a PDP-8, with a 32,000 word disk for storage of data. As shown in Figure 1, this machine has a number of peripheral devices attached to it. The data input is from a serial-to-parallel converter driven by telemetry bit synchronizers. This allows the computer to read each spacecraft word as it is received in the NASA control center. The status display panel is used to show the latest equipment status received. This display, used in conjunction with the predicted status panel, gives an immediate check on the gross functioning of

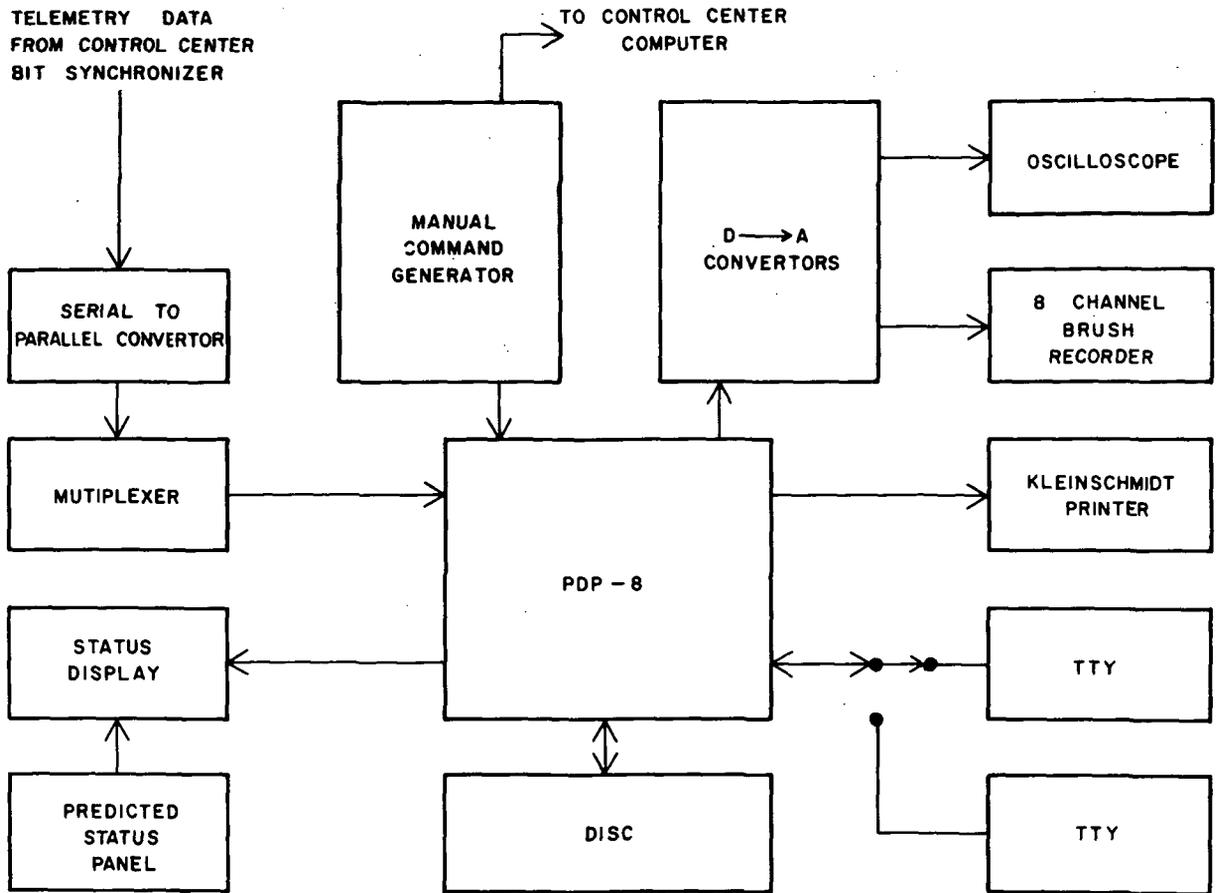


FIGURE 1. GOE BLOCK DIAGRAM

the equipment.

The recorder provides a permanent record of data signals and status voltages while the printer gives a hard copy of the data that was stored in the spacecraft memory and is temporarily stored on the PDP-8 disk. The teletype is used by the console operators to call in various phases of the processing and to override automatic processing that may be going on.

There is also a manual command generator whose function is to allow commands for the Wisconsin experiment to be generated and executed by the spacecraft on a real-time basis. This is used only in emergencies but is very valuable when needed.

## VIII. THE PROGRAM (REPTILE)

The operating program for the GOE was written by Mr. Terrel L. Miedaner and is built around a flexible monitor system operating under interrupt control. Several different types of data may come down from the spacecraft and the program must recognize the pertinent experiment data from the structure of the telemetry frame. This is done and all real-time status frames are displayed and sent to the chart recorder while any data storage dump is stored on the disk for later processing.

The teletype and command generator are monitored constantly while data analysis and printout are taking place if a data storage dump has been received. The monitor allows the operator to call for reprocessing of the data, reassignment of chart recorder channels, replay of data to try other possible formats, and various logging and time correlation functions.

The programs necessary to perform the service requested by any particular interrupt are rolled in from disk to the small core of the PDP-8 making this system a time-shared control computer system. The telemetry handling programs are resident in core necessitated by the high speed of data input (50KC).

It should be noted that all of the components of the spacecraft control center are represented here but in a very parochial sense in that we are concerned only with the experiment equipment on the spacecraft and therefore can concentrate on a small portion of the total monitoring problem just as the OAO control center does not concern itself with other satellites.

On a project as large as the OAO it is difficult to make judgments about the value of parts of a system but it is clear that the OAO observatory could not have functioned successfully without both the HARUSPEX control program and the Wisconsin GOE including REPTILE.

The authors would like to thank Carol S. Burkhalter, who wrote TWERP, and Terrel L. Miedaner who wrote REPTILE and parts of MAP and SLEW.

## REFERENCE

Heacox, H. C. 1970, M. S. Thesis, University of Wisconsin.

## SCIENTIFIC RESULTS OF OAO-2

## APPENDIX

```

..RUN PLOTS  NPA PORT
COMMENT *****
COMMENT * PLOTS RUN TO SHOW SKY CONDITIONS AT BEGINNING AND END OF *
COMMENT * NIGHT FOR MIDDLE OF WEEK. *
COMMENT * LEGEND: *
COMMENT *   F = DARK EARTH *
COMMENT *   / = SUNNY EARTH *
COMMENT *   . = SUN *
COMMENT *   ~ = ANTI-SUN *
COMMENT *   ) = MOON *
COMMENT *   P = CIRCLES ABOUT POLES OF THE ORBIT WHICH ARE NEVER *
COMMENT *         OCCULTED BY THE EARTH *
COMMENT * GUIDE STARS ARE INDICATED BY THEIR ASSIGNED NUMBERS. *
COMMENT * WITH THE RIGHT-MOST DIGIT MARKING THE STARS' POSITIONS. *
COMMENT *****
BEGIN AT 263 04 02
DELTAT 1
MAX NUM 32
NUM SETS 1
RADII 45.0 74.0 10.0
START

```

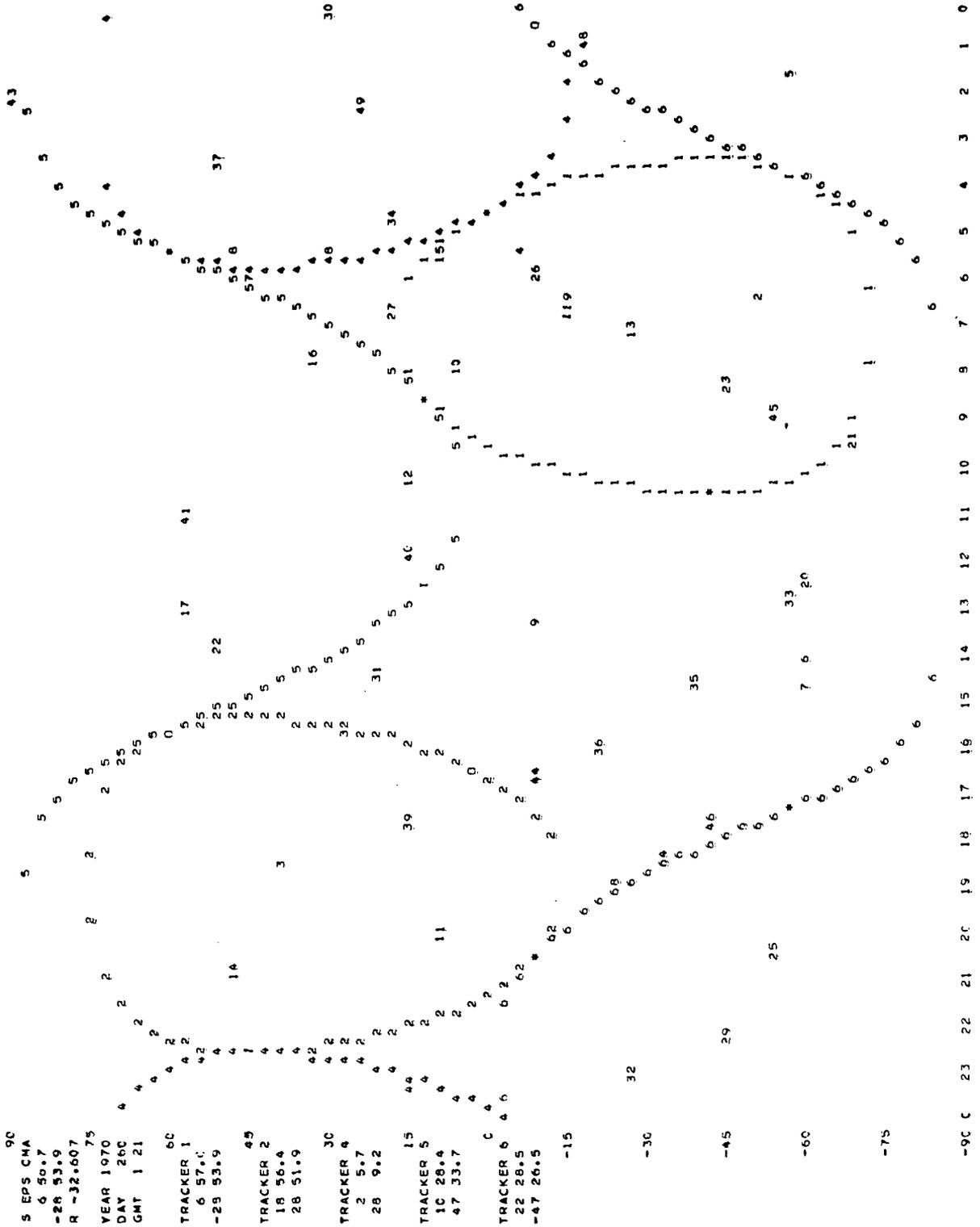
```

..RUN MAP
COMMENT *****
COMMENT * THE NEW FILE IS USED AS INPUT TO MAP, WHICH IS RUN FOR *
COMMENT * THE ENTIRE DAY. THE OUTPUT CAN THEN BE USED FOR MANUAL *
COMMENT * SCHEDULING OF OBSERVATIONS. *
COMMENT * LEGEND: *
COMMENT *   N = SPACECRAFT NIGHT *
COMMENT *   - = SPACECRAFT DAY OR STAR OCCULTED BY DARK EARTH *
COMMENT *   A = SOUTH ATLANTIC ANOMALY *
COMMENT *   / = STAR OCCULTED BY SUNNY EARTH *
COMMENT *   D = STAR UNOCCULTED AND BORE-SIGHT TRACKER USABLE *
COMMENT *   R = STAR UNOCCULTED AND BORE-SIGHT TRACKER NOT USABLE *
COMMENT *   R = ROSMAN GROUND CONTACT (GROUND CONTACT LINE) *
COMMENT *   O = ORRDAL GROUND CONTACT *
COMMENT *   M = MADAGASCAR GROUND CONTACT *
COMMENT *   Q = QUITO GROUND CONTACT *
COMMENT *   S = SANTIAGO GROUND CONTACT *
COMMENT *****
FILE IN 27
INITIAL 1
START

```







SATAN PLOT FOR ORBITS 9330 THROUGH 9334.

KEY TO ORBIT NUMBERS

SYM	ORBIT	TIME AT ASC NODE	SUNSET	SUNRISE
1	9330	157C 260 5 1 44	260 5 50 19	260 6 20 59
2	9331	197C 260 6 41 51	260 7 30 26	260 8 1 7
3	9332	197C 260 8 21 59	260 9 10 34	260 9 41 15
4	9333	197C 260 10 2 6	260 10 50 41	260 11 21 22
5	9334	197C 260 11 42 14	260 12 30 49	260 13 1 30

LONGITUDE SCALE IS 3 DEGREES PER COLUMN, LATITUDE SCALE IS 3 DEGREES PER LINE.  
POINTS ARE PLOTTED AT INTERVALS OF 2.5 MINUTE(S) FROM EACH ASCENDING NODE, WITH THE FIRST POINT AT THE NODE.

