THE OBSERVATION PLANNING FACILITY FOR THE INFRA-RED ASTRONOMICAL SATELLITE (IRAS)

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ABSTRACT

The mission objective of the Infrared Astronomical Satellite (IRAS) is to perform an all-sky survey in the infrared and to carry out additional observations on specific sources. This paper describes the software system that will generate and schedule observations to perform these two tasks.

Keywords: Observation planning, satellite control, satellite operations, IRAS satellite, command languages, B*-trees, database organisation, backtracking method.

1. INTRODUCTION

IRAS is a 3-axis stabilised infra-red astronomy satellite. It is due to be launched in August 1982 into a circular sunsynchronous twilight orbit at 900 km altitude. The scientific objectives of the mission are to carry out

- an umbiased survey of the infra-red sky with high degrees of completeness, reliability, sensitivity and photometric accuracy, and
- additional observation programs using the survey array and other IR-instruments.

It is expected that the survey will require roughly 60% of the time available for science observations, leaving 40% (ca. 2000 hr) for the additional programs.

The instruments are mounted in the focal plane of a 60 cm diameter telescope, together with the 8 detectorslits of a visible-star sensor used for attitude control and reconstruction purposes. The cassegrain telescope is constructed entirely from Beryllium and is kept at 2 K by 76 kg of superfluid Helium. This amount of Helium will yield a lifetime of approx. one year provided sufficient precautions are taken with regard to the pointing direction of the telescope to avoid excessive heatloads.

The satellite will be operated from a single tracking and control station located near Chilton, in the UK. It will be visible from the station around dawn and dusk on 3 consecutive orbits with pass-durations of upto 16 minutes. Therefore, it is necessary that the satellite can store a sequence of observations, execute these in a time-tagged manner and store the resulting science and ancillary data. To this end IRAS is equipped with an On-board Computer Subsystem, consisting of two processors, 64 Kwords of solid state memory and 2 taperecorders of 455 Mbits each. (See Reference 1.)

It is the task of the Observation Planning Facility to produce the aforementioned sequences of observations, otherwise known as the Satellite Observation Programs (SOPs). It has to generate the survey observations, additional observations and operational measurements (such as calibrations) and combine these in such a manner that no satellite constraints are violated, while the time lost in manoeuvering from one observation to the next is kept to a minimum. The task is complicated by the different nature of the 3 types of observations. The survey has to follow a strict pattern of repetitive coverage of the sky, with fairly rigid requirements on the repetition periods. The additional observations, on the other hand, normally have a large visibility window of upto months, as the 3-axis stabilised satellite allows a high degree of freedom in pointing the telescope (within the constraints). Instrument calibrations, and satellite performance checks in general, also have to be scheduled regularly with varying repetition periods ranging from orbits to months, but obviously with a lower priority than the survey observations.

A further complication arises from the international character of the project. Space agencies and astronomers from the USA, the UK and the Netherlands are involved. Agreements have been made with regard to the division of the time available for additional programs between the three nations. This necessitates the implementation of an accounting scheme in the Observation Planning Facility. Also, the facility must be reasonable easy to use by a large number of different users (astronomers, engineers and operations personnel) scattered throughout the world. Hence, much attention has been paid to the user-friendlyness of the system. It specifically allows almost "hands-on" control of the SOPs by the IRAS science community.

2. ATTITUDE MANOEUVRING

The coordinate system to describe the attitude of IRAS can roughly be defined as follows (Fig. 1):

X-axis: boresight of the telescope
Z-axis: perpendicular to the solar panels
Y-axis: completes the right-handed orthogonal system.

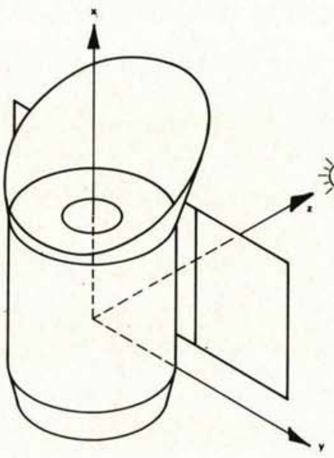

Figure 1. Satellite coordinate system.

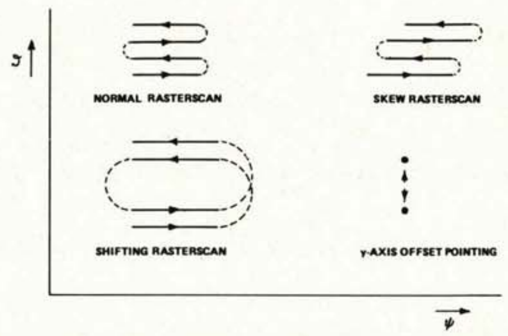

Figure 3. Examples of attitude manoeuvres.

The attitude control system keeps the orientation of the satellite such that the sun is in the X-Z plane (disregarding limit cycling). Consequently, the attitude of the satellite can be described by two angles (Fig. 2):
- solar aspect angle θ
- clock angle ψ.

The basic attitude manoeuvre is the scan, during which the angle θ is kept constant, while ψ decreases or increases uniformly. As a result the boresight describes a small circle, in a plane perpendicular to the satellite-sun vector. By setting the ψ-velocity to zero this manoeuvre degenerates into a pointing. The attitude control algorithms (implemented in the on board software) provides for more complicated manoeuvres, but they are all composed of scans or pointings. Examples are shown in Figure 3.

The angle θ is measured on board with the fine Y-axis sunsensor, which gives an absolute reference. The angle ψ is calculated on board from the outputs of the X- and Z-axis gyros and from the angle θ. The gyros essentially measure the velocity of the satellite around the X- and Z-axis. The calculation of ψ therefore also requires an absolute reference. This is provided by fine attitude calibrations in which the time is measured at which a known star passes the visual star sensor slits. These calibrations must be carried out quite frequently (2 or 3 times per scan) to account for gyro drift and for calculation errors on board. The fine attitude calibrations

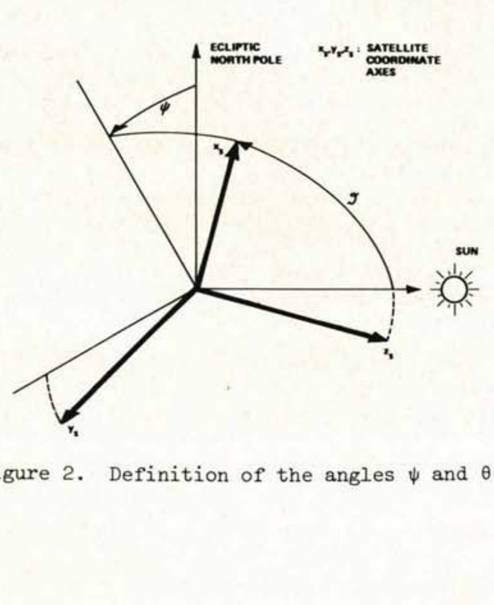

Figure 2. Definition of the angles ψ and θ.

are inserted automatically by the observation scheduling programs (section 7).

3. OBSERVING CONSTRAINTS

Two types of constraints are of particular importance when generating Satellite Observation Programs:
- constraints related to the attitude of the satellite with respect to the sun, moon, earth and various other planets
- constraints associated with the position of the satellite relative to the earth.

They are listed in Table 1. Details on some of them can be found in Reference 2. There are also restrictions of an engineering nature as to the use of the instruments or the capabilities of the attitude control system. Since these are relatively standard they will not be discussed further. They can be found in Reference 4.

The MOLD constraint (nr. 3 in Table 1) is a consequence of the cryogenic temperatures at which the focal plane and optical surfaces are kept. In fact, some deposition of atmospheric particles could be tolerated, but the accumulated layer should have a negligible effect on the performance of the instruments.

Constraint 4, apart from the straylight effect, is imposed by the recovery time of the detectors after they have been illuminated by very bright sources. The planets Mercury and Venus are too close to the sun to be visible for IRAS within constraint 1.
The design goal regarding susceptibility to proton radiation (constraint 5) is that protons above 50 MeV with flux levels below 10^3 $cm^{-2}s^{-1}$ should not have significant effect on the observations. This goal cannot be met and the actual flux limit is likely to be between 10 and $10^2 cm^{-1}s^{-1}$. The contour limits for these flux levels are indicated in Fig. 4 as taken from Reference 3. The effect of this constraint is particularly felt in the all-sky survey: it will often prohibit complete execution of required scans and, consequently, there will be gaps in the regular sky coverage pattern.
Electron radiation will only affect the detectors of the visual-star sensor and therefore lays constraints on fine attitude calibrations (constraint 6). As far as the electron radiation zones coincide with the proton radiation zones, this constraint has no effect because of constraint 5. Since there are additional electron radiation zones near the geographical poles (Polar horns), constraint 6 is a real one.

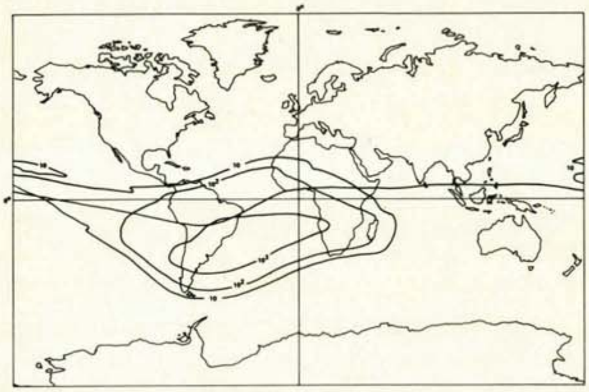

Figure 4. Flux contours proton radiation.

The reason for constraint 7 is that during a prime station pass a new SOP is loaded into the on board computer, while the data stored in the memory and on the on board recorder during the previous SOP is transmitted to the ground. Although these problems could be overcome, it appeared that continuation of observations would considerably complicate ground operations and data processing, particularly in not quite nominal circumstances.
The minimum scan length constraint (nr. 8) is based on the requirement that sufficient visible stars are found along the track to allow fine attitude calibrations.

The modelling of the above constraints is often quite complicated and sometimes impossible. In the latter case, the extent of the constraint can only be determined experimentally in orbit.

4. OBSERVATION PLANNING FACILITY OVERVIEW

The prime objective of the IRAS mission is to execute the all-sky survey but allow more detailed study of selected regions through additional (non-survey) observations. As with any satellite-borne instrument, time must also be spent in subsystem check-out and calibrations before and during data collection. In order to fulfil these aims of the mission an almost unbelievable 30,000 to 40,000 individual observations will be executed over the expected one year lifetime of IRAS. This lead, early in the mission design phase, to the idea of a sophisticated computer software package to ease the burden of defining, generating and scheduling this large number of observations. Such a facility has been designed and constructed at the IRAS Ground Station site at Chilton, UK, by a joint Dutch-British team.

The function of the Observation Planning Facility is to provide software tools to aid the definition and generation of observations and to schedule them into Experimenter's Target Lists (ETLs). ETLs are high-level, human readable versions of the aforementioned Satellite Observation Programs which are loaded, one per 12-hour period, into the IRAS on-board computer. An observation can be considered as a uniquely identified period of time within which the satellite attitude, instrument configuration and data collection mode are modified (within the constraints mentioned in section 3) according to the user's requirements.

There are basically four observation planning tasks:
1. Generation of survey observations.
2. Generation of non-survey observations.
3. Observation scheduling.
4. Observing time accounting and general administration.

These tasks are reflected in the modularity of the ETL Generation Assembly software design (Fig. 5), which is described in sections 5 to 7. To give an overall view, each will be described briefly below.

CONSTRAINT DESCRIPTION	REASON
1. Solar aspect angle constraint $60^\circ < \theta < 120^\circ$	- To prevent fatal heat input from the sun into the telescope. - Solar panel illumination. - Range of the fine sun sensor.
2. No IR-radiation from the earth into the telescope.	- Heat input into the telescope. - IR straylight.
3. Relative wind of the orbital motion may not blow on interior of the telescope.	- To prevent freezing of atmospheric particles on cooled surfaces (Molecular Deposit or MOLD constraint.
4. Boresight direction must be kept away about 24° from the centre of the lunar disc and about 1° from the planets Mars, Jupiter and Saturn.	- Straylight. - Saturation of detectors by bright sources.
5. No observations while passing through zones of high proton radiation.	- Background noise.
6. No fine attitude calibration while passing through a zone of high electron radiation.	- Increased noise in visible star sensor
7. No observations during prime station passes.	- Interference with operational activities.
8. The length of a scan must be greater than (nominally) 20°.	- To make it sufficiently sure that stars can be found for fine attitude calibrations.

Table 1. Constraints for observation planning.

4.1 Generation of survey observations

The survey observation generation process is, by necessity, almost fully automated and so once the desired survey strategy is defined, the observation scans for the complete survey will be generated and stored awaiting scheduling. It will, therefore, require little maintenance and the workload on the project scientists and mission planners will be small, releasing them to monitor the quality and progress of the survey and, of course, to concentrate on the additional observing programs.

4.2 Generation of non-survey observations

The non-survey observation generation process has to meet the needs of three sets of users:

1. Scientists who wish to use the instrument to collect infra-red data.
2. Spacecraft and telescope engineers who will perform the initial checkout, health monitoring and fault diagnosis of the on board hardware and software systems.
3. Operations personnel who will perform initial and routine calibration of the instrument and related hardware.

One of the major features of the system is that it is interactive and users will be able to have practically unrestricted access to it, thus being able to define observations at will and know that even at short notice (as little as six hours) important observations will be scheduled. This is of special importance during the in-orbit-checkout phase which will occupy the first three weeks after launch. The checkout sequence is very compactly scheduled in order to allow science data collection to start as soon as possible. During this phase it is most likely that rescheduling will be necessary. It is also of great value to observers not resident at the Chilton site who can link into the system from remote sites in the USA or the Netherlands at times convenient to line availability and normal working hours.

Obviously such a system could easily become unmanageable, overburdening the observation scheduling process by supplying vastly more observation candidates than there is time available and would not guarantee fair distribution of time among observers, so that some sort of control must be imposed. This is done by allocating restricted observing time to authorised observers (the time being allocated by the national agencies NASA/NIVR/SRC) which is accounted by the Accounting System. Also, observations are initially made "inactive" (i.e. not considered by the scheduling system) when first defined. The "activation" is controlled by a project scientist known as the Resident Astronomer who is permanently based at the IRAS Ground Station (with his team of assistants) to deal with this and other science related problems.

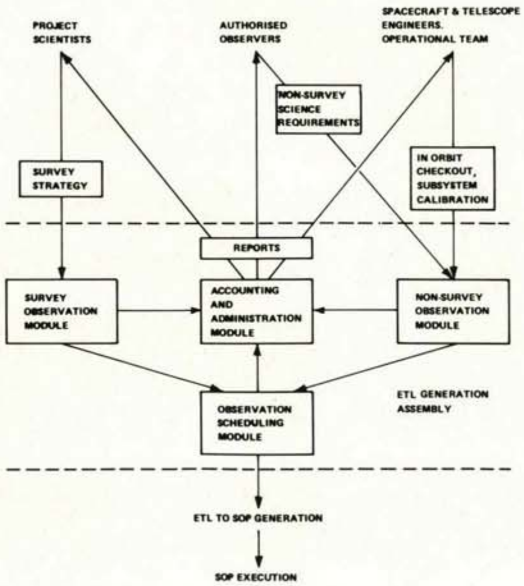

Figure 5. The ETL Generation Assembly.

To increase scheduling flexibility, observations defined this way are not required to be (but may be) time-tagged; that is, the observer has merely to define the sky area of interest and the observation will be scheduled at a time that area is visible. In order to provide a means by which the observation sceduling software may make judgements on the relative merits of observations, each has to be assigned a scheduling priority rating. This task is done by the Resident Astronomer based on agency (NASA/NIVR/SRC) and observer assigned ratings. This individual is in the unenviable position of having to be both scientifically and operationally aware, therefore, and from day-to-day make decisions which try to reconcile the scientific demands with the operational situation.

4.3 Observation scheduling

It is also the Resident Astronomer who will run the observation scheduling system (although ultimate control lies with the Mission Operations Manager)

Observation type	Generation module	Priority
emergency operational	non-survey	1
survey	survey	2
survey recovery	survey	3
calibration	non-survey	4
non-survey science	non-survey (active)	5
non-survey science	non-survey (inact.)	n.a.

Table 2. Observation scheduling priority order.

and, although it is an almost fully automated process, he can be expected to have to make decisions on the final contents of the Experimenter's Target Lists when non-nominal situation arise.

Due to the high number of observations and the relatively short mission lifetime, it is important that efficient use is made of the available observation time. The observation scheduling software, therefore has to select observations for ETLs such as to optimise the useful observing time; that is, to minimise overheads such as manoeuvering the satellite between observations. The technique used is that of assigning priorities to observations and scheduling them accordingly (Table 2). In all cases except the non-survey science observations conflict between observations with identical ratings must be resolved manually by the Resident Astronomer (for science observations) and the Mission Operations Manager (non-science observations). For the additional science observations the priority rating is only one factor used in the selection process and in the unlikely event of a conflict it is resolved without involving the RA or the MOM, although warnings are generated when rejected observations are in danger of not being scheduled at all.

In order to allow the manual resolution of conflicts and to maintain control over the scheduling system, a mode is provided whereby the Resident Astronomer and Mission Operations Manager (or their assistants) can manipulate an ETL to achieve the desired makeup. Observations can be inserted, altered or deleted, the system ensuring that the final ETL is still valid with respect to the observing constraints. This, again, is a feature which may prove very useful in the in-orbit-checkout phase when short notice alterations to ETLs may be necessary.

Report	Contents	Output option	Uses
Long Term Forecast	Survey observation details and timelines.	lineprinter VDU	Monitoring planned coverage Aid for non-survey observation planning.
Non-survey observation	Details of planned non-survey observations.	lineprinter VDU	Manual validation.
Observation History Summary	List of executed non-survey observations.	lineprinter VDU	Observer and Ops. reference.
Observing Time Account	Observing time used by each observer.	lineprinter VDU	Resident Astronomer reference.
Short Term Forecast	Detailed timeline of scheduled observations.	lineprinter VDU	Scheduling efficiency monitoring and aid to manual scheduling.

Table 3. Accounting and administration module reports.

The task of the scheduling module is not only that of selecting observations generated by the survey and non-survey modules. Observations, especially those for the survey, must be accompanied by fine attitude calibration sequences to enable accurate attitude reconstruction on the ground and also to update the attitude estimate by the on board computer. For this purpose a large catalogue of visible stars down to 10th magnitude has been compiled and is used to find 2 or 3 stars suitable for the calibration of each observation.

4.4 Observing time accounting and general administration

As has been mentioned above, each authorised observer is allocated observing time which is accounted by the system. If he exceeds his allowance, he is still allowed to define observations but they will not be activated by the Resident Astronomer until he is awarded extra time by the agency concerned. The accounting and administration module also provides facilities to produce the reports given in Table 3.

4.5 The observation planning hardware environment

The computer on which the Observation Planning facility is run is an ICL 2960 mainframe at the Chilton site and is dedicated to IRAS operations. Apart from this facility, the machine is host to other software required to drive the project (e.g. orbit determination, engineering data analysis, quick-look science analysis) and will be quite heavily loaded at the peak processing times. These occur immediately post-pass when the telemetered science and engineering data is processed. The basic configuration is shown in Figure 6.

The operating system (GEORGE 3) provides automatic protection for data held within system recognised filestore by regular transfer to magnetic tape of new or updated files. However, large files such as many of these required in the Observation Planning Facility are so-called exofiles, external to filestore and therefore not protected by the system. Special procedures have been invoked to make regular security copies of these files, so that in the event of system failures a minimal amount of work is required to restore the observation planning files to their former status.

5 SURVEY OBSERVATIONS

The all-sky survey is performed by scanning the sky in a systematic, well defined way. This, and the complicated nature of the constraints to which observations are subjected, made it necessary to automate the generation of survey observations. The program that will perform this function is GAS: the Generation Aid for the Survey.

Inevitably some datalosses of survey observations will occur from time to time, for various reasons. To patch the holes in the sky coverage that are caused by these losses, a semi-automatic program is available: SURE (Survey Recovery).

5.1 Survey strategy

In the all-sky survey each part of the sky will be

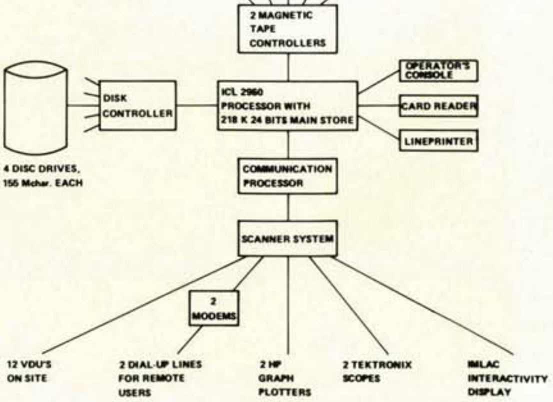

Figure 6. The IRAS batch computer at Chilton.

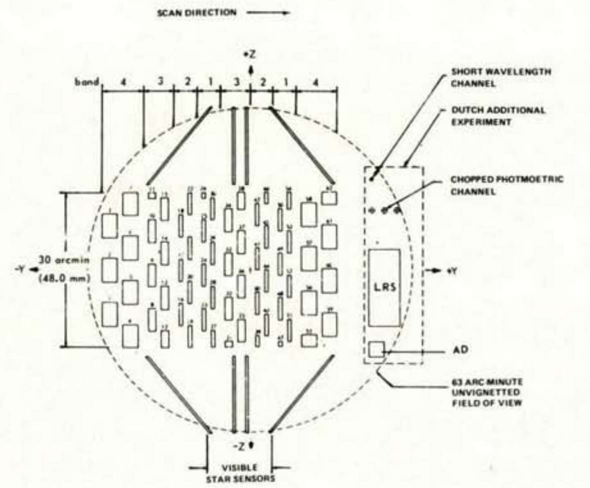

Figure 7. IRAS focal plane layout.

scanned several times with intervals of various timescales: seconds, hours and weeks. This is dictated by requirements on the following aspects:

- completeness of the final catalogue: i.e. the fraction of all IR-sources (above some S/N level) that appear in the catalogue
- reliability of the final catalogue: the fraction of sources in the catalogue that corresponds to actual IR-sources.
- preclusion from the catalogue of moving objects, such as asteroids and "space junk"
- photometric accuracy in the catalogue
- determination of variability of IR-sources.

To illustrate how the redundant scanning is achieved, the baseline survey strategy is described below. Redundancy with an interval in the order of seconds is obtained by the layout of the detector array in the focal plane (Fig. 7). For each wavelength band there are two rows of detectors. A source will pass these two rows with some seconds interval. By overlapping scans of subsequent orbits by half the swathwidth, each part of the sky is covered twice with an interval of one orbit (103 mins). The overlap at the ecliptic poles will, of course, be larger than at the ecliptic as the scan plane rotates with the sun. A part of the sky covered this way is denoted as "hours-confirmed" in the IRAS-jargon.

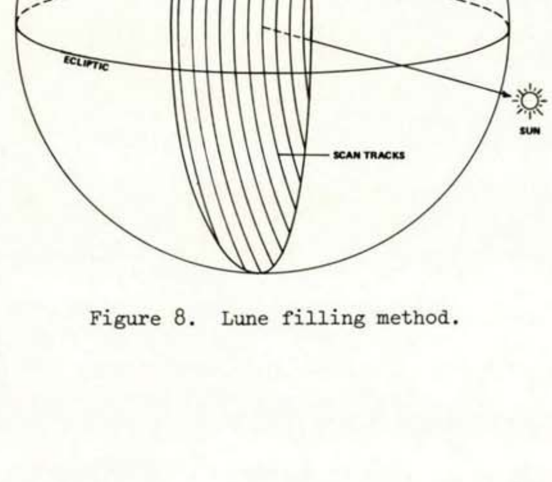

Figure 8. Lune filling method.

The length of the scan is taken such that a lune-shaped area, bounded by two ecliptic meridians, is filled up. This is done in the western and the eastern hemisphere concurrently (Fig. 8). The size of these lunes is such that it will take 2 to 3 weeks to cover them. The lunes that are subsequently covered will overlap for two-third. As a result each part of the sky will be covered three times "hours-confirmed" with intervals of several weeks.
Unfortunately, the above scheme cannot completely be executed, as constraints may sometimes prohibit to point in the required direction. A particular problem in this respect is the area of high proton radiation, the South Atlantic Anomaly. It can interrupt a scan long enough to prohibit picking up the scan track after emerging from the Anomaly. Though the effect of the constraints can be minimised by carefully tuning the strategy, some gaps in the coverage of the sky will be inevitable.

5.2 Handling data losses

Small data losses are likely to occur quite frequently, e.g. by transmission errors during data dumps. Larger data losses, in the order of one orbit or more worth of data, should occur far less frequently. To cope with small data losses, a number of orbits (nominally 2) per day are not used by the survey. They are the so-called recovery orbits. Initially they will be filled with non-survey observations, which are canceled, when necessary, to be replaced by survey recovery observations. Because the scan plane rotates with the sun, a failed scan part cannot be recovered by simply repeating the scan. Instead, a number of small scans are required to recover the missed part of the sky.

Larger data losses cannot be accommodated by this method. Instead, the survey has to be started again from the failed part onwards. This means that all observations, including the non-survey observations, of many months have to rescheduled. Clearly this method is far too laborious to apply it to small data losses.

5.3 The program GAS

The redundancy requirements of the baseline survey strategy described above are based on presumptions regarding the infra-red sky and regarding the performance of the instrument in orbit. So it is quite possible that - after launch - these requirements will change. The program GAS, that generates the survey scans, must therefore be capable of generating various strategies. To accomplish this, the program implies a parameterised strategy. The main parameters are shown in Table 4.

Because of core and runtime limitations, one run of the GAS program can produce scans for a period of up to two weeks. The scans are accumulated on a file. To generate scans for a complete survey about 16 runs are required.
In a GAS run the following steps are performed (Fig. 9):

1. For all scans the ecliptic longitude of ecliptic crossing is determined. The scan is allocated to an orbit and the solar aspect angle θ of the scan (determined by the longitude) is checked.

The sequence of step 2 through 5 is executed for each scan.

2. Calculate the length of the scan by determining the intersections with the lune boundary.
3. Determine the constraints of the scan. As the solar aspect angle θ of the scan is correct. (see

Parameter	Description
λ_{Ei}, λ_{Wi}	Ecliptic longitude of the start of the first lune of the survey in the eastern and western hemisphere
$\delta\lambda$	Overlap in ecliptic longitude of two subsequent scans
$\Delta\lambda$	Difference in ecliptic longitude at the start of subsequent lunes
N_{ST}	Number of scans in a lune
IH_{RECV}	Indicates how recovery orbits must be selected: $IH_{RECV}=1$: Select per SOP L_{RECV} recovery orbits, starting at the N_{RECV} -th orbit of the SOP $IH_{RECV}=2$: Starting in orbit I_{RECV} select L_{RECV} recovery orbits per N_{RECV} orbits. $IH_{RECV}=3$: Per day take as recovery orbits the L_{RECV} orbits most affected by radiation zone passages.
L_{RECV}, N_{RECV}, I_{RECV}	See IH_{RECV}

Table 4. The main survey parameters

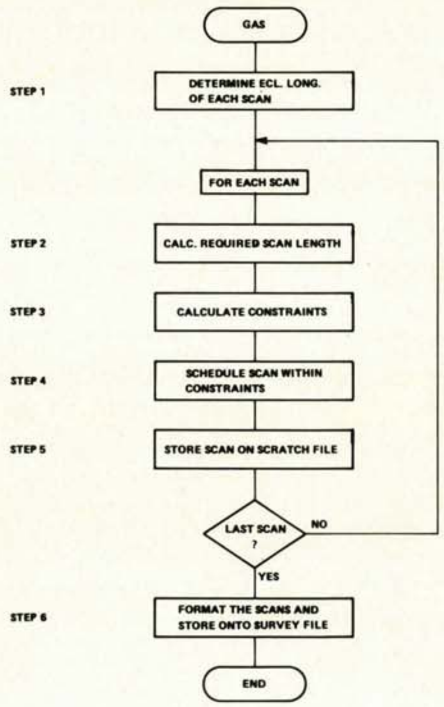

Figure 9. The program GAS.

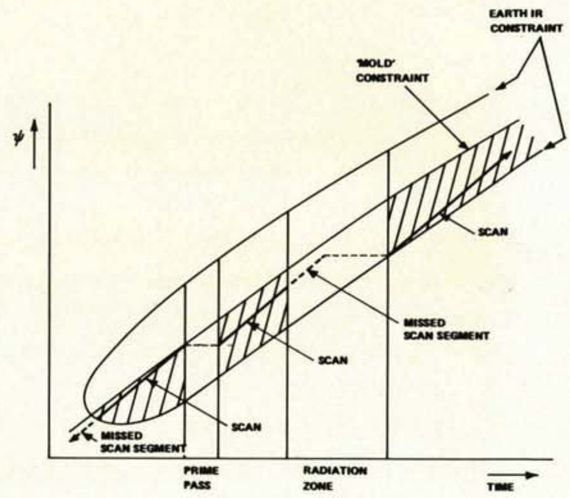

Figure 10. Example of scheduling a scan

step 1), there are only constraints in clock angle ψ and in time.
4. The scan is scheduled within the constraints. If necessary, the scan is broken up or shortened. An example is shown in Figure 10.
5. The scan is stored onto a scratch file.

When step 2 through 5 have been executed for all scans, the follwoing is done:
6. The scans are formatted and stored onto the survey file, which is input to the observation scheduling module.

5.4 The program SURE

When data of a scan has been lost, the gap in the coverage caused by such an event cannot simply be recovered by repeating the failed scans (or part of it). The scan planes are perpendicular to the satellite-sun line and, moreover, it will operationally take 24 to 36 hours before the recovery scans can be executed. Henceforth, the angle between the plane of the failed scan and the plane of the possible recovery scans will be 1° to 1.5°. Recoverey can therefore only take place by a number of short scans covering the failed scan or part of it (Fig. 11).

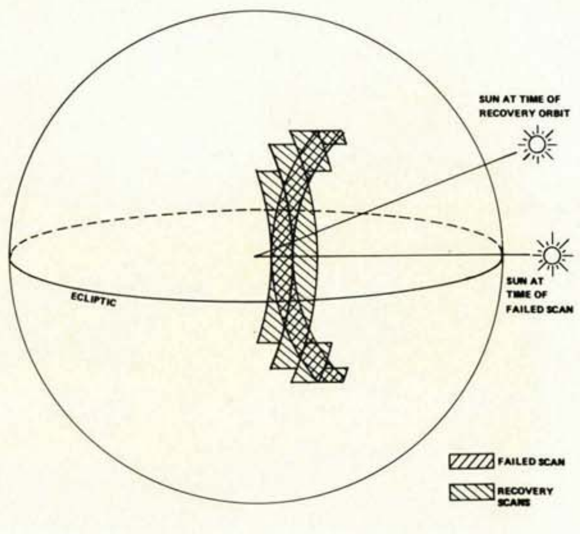

Figure 11. Covering a failed scan by recovery scans.

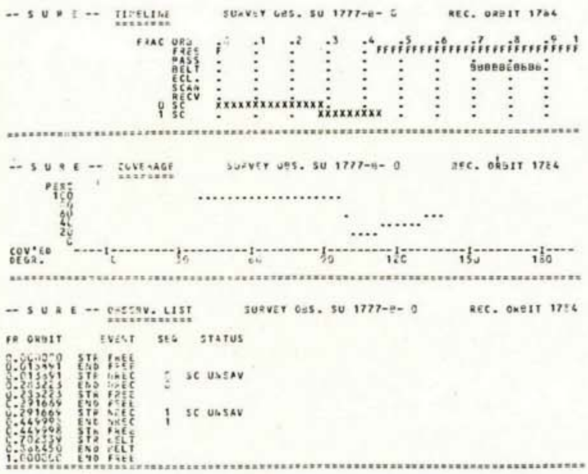

Figure 12 Example of a SURE session

The program SURE performs the task of finding recovery scans in a semi-automatic way. The user has to indicate to the program:
- which scan is to be recovered
- the part of the scan to be recovered
- the orbit in which recovery must take place.

SURE then generates the recovery scans, trying to recover as much as possible. The user has several amendment options:
- define an additional recovery orbit (if the recovery is not yet complete)
- delete a recovery scan
- shift a recovery scan in time, within the same orbit
- shorten a recovery scan.

The program provides the user with some simple aids on alpha-numeric display (Fig. 12):
- a timeline of the recovery orbit, showing time constraints (e.g. passage of radiation zones) and the scans
- a coverage plot giving the percentage of recovery along the scan
- a time ordered list, giving the accurate start and end times of the events shown in the timeline.

6. NON-SURVEY OBSERVATIONS

The Non-Survey Observation (or Additional Observation) module is the tool that enables the authorised astronomer to define his observations for inclusion into the Experimenter's Target Lists and, ultimately, into the Satellite Observation Programs. This module also plays an important role in the definition of the special observation sequences required during the in-orbit-checkout phase. Last, but not least, the module is used by the operations crew to define operationally required observations, such as diagnostic data taking.

Since this highly interactive system has to cope with quite a large number of options, a generalised Command Language Structure (CLS) has been devised. Before continuing the description of the additional observation definition system, it is worthwhile to deal with the main concepts of the Command Language Structure and associated software. Below the general CLS command will be described. A detailed definition of the CLS can be found in Reference 5.

6.1 The general CLS command

The command consists of upto 12 directives (4 letter mnemonics). The first directive is called the KEY-directive. Each directive may be followed by a parameter-list of upto 6 parameters. For example:

KEY=(p-list) DIR1=(p-list) DIR2=(p-list)

A parameter can be any of the following types: real, integer or a string of upto 8 characters. Each parameter has a name, which may be omitted. E.g.

ATT POS=(RA= right asc., DEC= declination) or
ATT POS=(right asc., declination).

Directives may be entered in any order, except for the KEY which has to be first in each command. Parameters may be entered in any order if the parameternames are used, otherwise a fixed order is required. All commands mentioned hereafter are defined to fit this format.

A set of commands is called a specific CLS. The set used in the non-survey observation definition process is known as the Observation Input Language (OIL). The CLS concept also allows to predefine command sequencing, conjunct and/or disjunct parameters of the same directive. Commands, directives and parameters may either be optional, required or defaulted (Reference 5). The completely specified command set is stored onto a discfile which can contain upto 20 different sets. It is evident that the CLS concept is a flexible tool for providing tailormade special purpose command sets.

The commands entered are dealt with by a separate program that decodes and syntax-checks each command according to its definition on the CLS file. The command interpreter module (COIN) hence relieves the user program from dealing with the keyboard input. COIN interfaces with the user program via a labeled commonblock which contains mainly the KEY-number, the directive numbers and the parameter values of the command entered. The user program, however, has the option to prompt via COIN for parameters which were found to be in error. COIN itself will prompt for any omitted command, directive or parameter that has been defined as required and does not have a default value. This system effectively decouples the user program from the keyboard and results, in general, in a more modular program that therefore is easier to develop and maintain than otherwise would be possible.
To complete the design with respect to command handling, a macro definition module (UPMAF) has been developed which enables the user to define parameterised macros of any of the command languages stored on the CLS file. The macros may be nested. To this end, COIN is equipped with a macro-expansion module. Both COIN and UPMAF are to be looked upon as utilities and are used in a variety of interactive programs developed for IRAS ground operations, such as the aforementioned SURE. Due to its general nature the CLS software can well be applied to other projects that require interactive programs.
With respect to the Observation Input Language for IRAS, the macro definition module provides the astronomers with a powerful tool to pre-program standard parameterised observations (or part of observations), greatly reducing the amount of time spent behind a computer terminal.

6.2 The macro-generator, UPMAF

UPMAF is driven by a CLS-type command set. It can be used in two modes:

6.2.1 The auto-parameter mode. In this mode it is not necessary to define the macro parameters prior to specifying the macro body. The parameter-list is assembled during the macro definition process itself. A macro parameter can be any parameter of the CLS in use (e.g. OIL) by replacing that particular parameter by a name of upto 4 characters, preceded by an ampersand ("&"). The auto-parameter mode allows upto 11 different parameters per macro. In fact, a CLS type command description is defined with upto 11 different directives, each containing one parameter.

6.2.2 The group parameter method. This mode offers the possibility to attach a name to a group of parameters (upto 5 per group). In fact, a CLS type directive with parameter-list is created. This mode is quite useful to tag a group of related parameters. However, the group- and the parameter-names have to be predefined. The group parameter method allows upto 11 groups of upto 5 parameters each to be specified (55 in total).

Effectively, the macro-generator creates a command description for each macro similar to the ones used by the CLS system. Macro definitions are stored on the macro-file. As soon as COIN encounters a macro statement, it will decode its name and retrieve the correct command definition from the macro-file rather than from the CLS file. It will treat the macro definition in exactly the same way as a CLS command definition.
It is correct to state that each macro definition extends the pertaining command set with an additional command, being a combination of the original command set and/or previously defined macros.

6.3 Observation Input Language definition

In this section OIL will be discussed in more detail. The actual software will not be described extensively since most of the constraint checks (geometry, earth IR, MOLD and bright objects) are essentially similar to the ones discussed in section 3.
The OIL commands can be divided into two subsets:
- additional observation definition, 15 commands
- program directives, 6 commands.

These subsets are defined in Table 5 and 6 respectively. A complete OIL description can be found in Reference 5. As an example of the OIL options, the "OBS" command will be explained in section 6.5 as it gives a good impression of the use of conjunct/disjunct directives.

One further command is available in OIL: the macro-command MAC. As explained earlier, this command

OBS	observation header
ATT	attitude mode
MES	measurement block
EDH	experiment data handling
TSY	telescope command
(BLVL)	telescope bi-level command
DAX	command for Dutch Additional Experiment
(SDS)	special data storage
(TTC)	time-tagged command
(SCF)	sensor configuration
(FCAL)	fine attitude calibration
(CCAL)	coarse attitude calibration
CMT	comment
EATT	end of attitude block
EOBS	end of observation
	(...) means not available to astronomers

Table 5. Additional Observation commands.

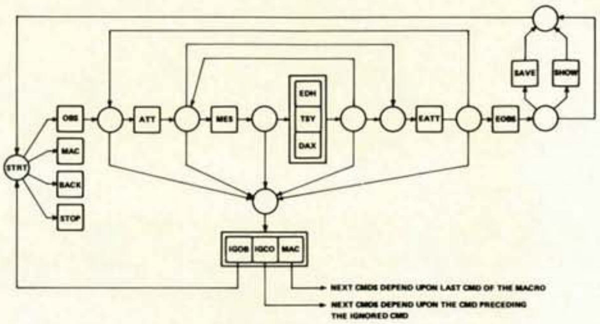

Figure 13. OIL command interrelation.

SHOW	displays the last observation defined
SAVE	saves the last observation defined
IGCO	ignores the previous command
IGOB	ignores the observation being defined
BACK	go back to main program
STOP	finishes the session

Table 6. OIL program directives.

causes a predefined observation macro to be entered into the input stream and, subsequently, to be expanded. Omitted parameters are prompted for.

The interrelation of the OIL commands is shown in Figure 13.
Table 7 shows the general structure of an additional observation. The observation starts with the OBS statement which amongst others gives it an unique identification composed of the astronomers initials (2-letter code) and a sequence number. It is concluded with the End Observation (EOBS) statement. The body of the observation is composed of one or more attitude blocks.
An attitude block starts with the attitude statement (ATT) which amongst others specifies the attitude type, scan or rasterscan; the equatorial position to look at and the scan speed. It is concluded with the End Attitude Statement (EATT) which specifies the duration (in time) of the attitude block. The attitude block body is composed of zero or more measurement blocks.
A measurement block begins with the measurement statement specifying at what time (relative to the start of the attitude block) the following commands are to be executed.
A measurement block body may contain:

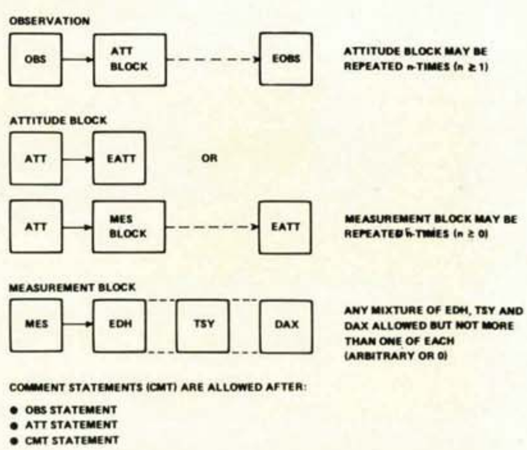

Table 7 Additional Observation Structure

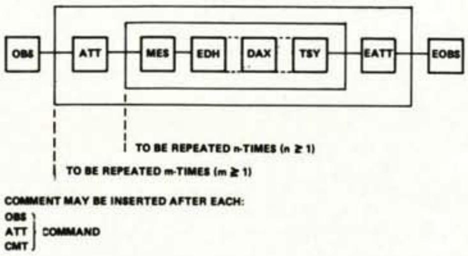

Figure 14 The complete additional observation

EDH (Experiment Data Handling) command
TSY (IR-Telescope) command
DAX (Dutch Additional Experiment) command
The complete additional observation is shown in figure 14.
The additional observation definition is but one of four operations allowed by the Generation Aid for Non-Survey definition (GANS).
The other functions facilitate to change the ratings of the three priority systems mentioned in section 5.1, and to produce a detailed printout/display of the contents of stored observations. In general a particular astronomer has only access to his own observations. The Resident Astronomer, however, can access all observations.

6.4 OIL options

This section will discuss some of the major OIL options connected with the OBS command. OBS command has the following main directives:
WDOW=(ORB MJD UTCS,start,end) } disjunct
ETL=etlnumber } disjunct
STRT=(ORB MJD GMT ,start)
The WDOW option enables the astronomer to specify a window in terms of:
- orbits
- MJD (Modified Julian Date)
- UTC (Universal Time Coordinated)

GANS will check if the given observation is indeed visible during this window and where necessary reduce the window. The effect is that the observation will only be considered for inclusion in the ETL/SOP's covering or being covered by this particular window.
If not specified a maximum (calculated) visibility window in terms of orbits will be supplied. The same is valid if one of the limits remains unspecified UTC and MJD windows are always converted into orbits. The ETL option specifies a window in orbits spanning the period covered by the specified ETL number.

With the STRT option it will be possible to precisely time-tag the start of an observation. Again the time-tag is specified in either fractional orbit, MJD or UTC time. This option is useful if one wants to coordinate his measurement with a ground based observation. An option which will not be described in detail is the capability to specify position and scan velocity in attitude sensor (e.g. GYRO or FSSY Fine Solar Sensor-Y) set points rather than in equatorial coordinates and a scanspeed in arcminutes per second.
This mode of observation definition will be extensively used during the In Orbit Checkout (IOC) phase to measure the performance of the attitude sensors and actuators and various misalignments precisely.

6.5 Observation Administration

Figure 15 gives an overview of the elements and the cross connections of the observation administration- and the additional observation database. It consists of the following elements.

1. The AO database directory (AOF file cluster)
The number of observations expected is extremely large, some 20.000 to 25.000.
Retrieval speed is of the utmost importance. The ETL scheduling software has to access quite a lot of observations in order to fill the gaps in the ETL left by the survey scans and the survey recovery scans. For any given gap a large number of observations may qualify, all of them have to be accessed and assessed upon minimum scheduling cost (Ref. section 5.4).
Therefore a multiple tree structure known as a B* structure has been selected for the AOF main- and subdirectory files (Ref. 6,7,8). A second reason to select this B* tree system is that it also features sequential retrieval of keys, which is very useful in combination with the administrative printout/display facility.
The subkeys such as object name, visibility orbit, position allow quick retrieval of Additional Observations upon almost any combination of subkeys or subkey ranges.

2. Observation history
This database is divided into a SOP related history file containing SOP and station pass related information, for the operations crew, and an observation related history file. The latter file stores amongst others the technical data quality and the attitude calibration success, indicating the positional reliability of the observation. This file can be interrogated by the experimenters in order to assess the success of their observations. The astronomer has the facility to enter comment e.g. with respect to obtained scientific results.
Both files are updated post pass using data obtained by the post pass data processing system.

3. Observation time accounting
This system keeps track of the time spent by each astronomer of each of the participating agencies and compares this time with the time slice allocated to him by his agency.
Violations are flagged where upon the RA may exclude the astronomer(s) concerned from executing further observations or after consulting the appropriate agency may adapt the allocated time slice.
Also recorded are observation overheads (slew times) and data losses due to telemetry faults.

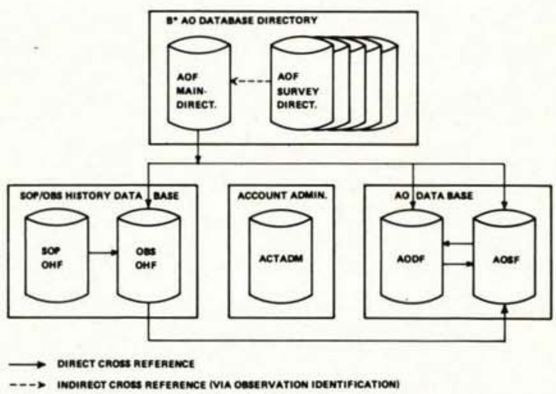

Figure 15 Additional observation and OBS-administration data base

The accounting system maintains several accounts:
. accumulative personal account
  - from launch onwards
  - from a RA defined date onwards
  - per SOP period
. accumulative accounts for each participating agency.

The accounts are updated after each:
- ETL generation
- SOP generation
- prime pass data dump.

6.6 Administrative printout facility
This facility makes to a great extend use of the Additional Observation File directory system which is cross-referenced with the observation history system. It is capable of producing three types of summaries:
- Observation accounting summaries
- Observation history summaries
- Additional Observation summaries.

7. OBSERVATION SCHEDULING

The task of the Observation Scheduling module is to compile Experimenters Target Lists from the survey and additional observations generated by the survey and non-survey modules. The requirements are that:
1. Survey observations are given preference over all non-survey observations except those needed for operational emergency situations.
2. Any spare time left in ETLs is filled with non-survey observations such as to optimise the useful observing time achieved.
3. Each observation is provided with attitude calibration sequences to enable accurate attitude reconstruction on the ground and to update the on-board computed attitude.
4. The creation of ETLs is an automatic feature but manual control of the ETL generation process is possible.

The sequencing of the scheduling tasks is shown in figure 16. The tasks break down into three convenient parts for which separate programs have been written. The programs, collectively known as REGEN (Resident Astronomer's ETL Generation package) will now be described in detail.

7.1 Task 1 - Automatic Survey Observation Scheduling
By the nature of the survey observation generation process (program GAS, see 5), the observations are time-tagged such as to fall neatly within the span of an ETL and do not violate any constraints, leaving the main tasks as those of selecting suitable stars for attitude calibration using the visible-star sensors and scheduling attitude calibration sequences. A large star catalogue has been compiled by Groningen University Space Research Department for this purpose (ref. 9) and contains details of

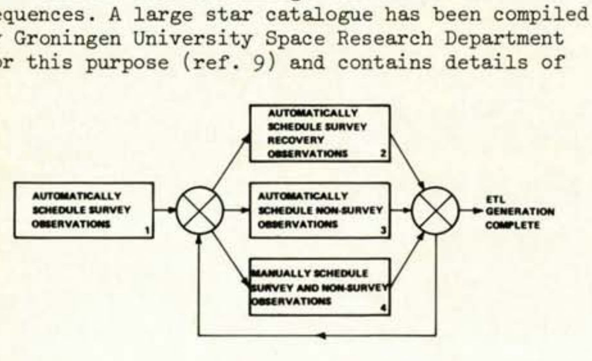

Figure 16 ETL Generation Task execution sequence

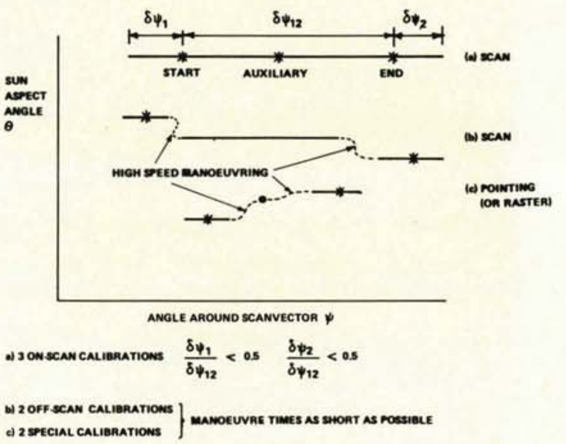

Figure 17 Attitude Calibration Sequences

over 1,000,000 stars down to the 10th magnitude. About 40,000 of these are candidate calibration stars (down to 8th magnitude), the remainder being possible disturbing stars (stars within 4 degrees of and brighter than or down to 3 magnitudes fainter than the calibration star with which they are associated, which, if detected by the star sensors during a calibration sequence would produce false results).
To meet the attitude reconstruction accuracy requirement for the survey (30 arcsecs) each scan must have at least 2 (one at each end) and ideally 3 calibrations (see figure 17). Unfortunately, the star sensor sensitivity requirement for detecting 8th magnitude stars is unlikely to be met requiring that special procedures are implemented to ensure sufficient calibration stars will be found. These include extending the scans to find sufficient stars on the scan track or, as a last resort, using stars off the scan track for special calibration sequences before and/or after the scan. Figure 17 shows the various possibilities. Such procedures can lead to conflict with neighbouring observations and attempts are then made to shift the scans in time. An additional constraint is the susceptibility of the star sensors to regions of high electron flux when calibration sequences are forbidden and inevitably there will occur scans for which insufficient calibrations are available. Such scans are not rejected but may result in less accurate data being included in the IRAS IR catalogue.

7.2 Tasks 2 and 3 - Automatic survey recovery and non-survey observation scheduling

ETLS created by execution of Task 1 (7.1) and Task 4 (7.3) (and perhaps amended by previous execution of Tasks 2 and 3) are amended in the following way:
1. Non-survey operational (emergency) observations are inserted, conflicting observations being deleted.
2. Survey recovery observations and their attitude calibration sequences are inserted, lower priority conflicting observations are deleted.
3. Other non-survey observations are selected, modified to include attitude calibration sequences and inserted such as to efficiently use remaining observing time.

The attitude calibrations are generated in a manner similar to that described in 7.1 (see Fig. 17).
The most important feature is the non-survey observation selection algorithm which attempts to fill unused observing time (gaps) as efficiently as possible. Various techniques from sequential assign-

ment to complex job-scheduling were examined, each having advantages (in terms of simplicity or optimal solutions) and disadvantages (inefficiency or heavy use of computer time and storage). The backtracking method was selected as best suiting our needs for the following reasons:

1. Efficiency levels for gap filling can be varied (trade-off between efficiency and computer time, changeable at will).
2. It can be combined with human interference in a natural way.
3. It is robust with respect to input changes.

Two quantities are central to the method:

1. The scheduling cost of an observation
   $C = C_o + \alpha A(idle) - \beta B(weight) + \gamma C(slew)$
   where
   C_o = some constant ensuring $C \geqslant 0$
   $A(idle)$ = some function of unused observing time caused by scheduling the observation
   $B(weight)$ = some function of relative preference (priority)
   $C(slew)$ = some function of the time required to manoeuvre from the previous observation
   α, β, γ = balance coefficients

2. The maximum cost threshold

$$M = M_o + D \text{ (observing time)}$$

   M_o = some constant
   D = some function of observing time so far scheduled.

The selection algorithm for filling a single gap is given in figure 18. Four alternatives exist for dealing with gaps which are unfilled.

1. Allow backtracking from gap to gap (within 1 or more ETLs)
   this will result in higher efficiency but is time-consuming.
2. Change the observation costing and/or cost threshold parameters to allow less optimal gap-filling
3. Manually select observations to fill the gaps.
4. Ignore them - this may be efficient as new observations are continually being generated and the gaps may be filled during later runs.

7.3 Task 4 - Manual selection of observations

ETLs may be created or existing ETLs amended manually from survey, survey recovery and non-survey observations. Attitude calibration of observations is possible only by using the automatic feature as used in task 1-3. Manual generation of attitude calibration sequences is possible only in the GANS facility (see 6) and will be used during in-orbit checkout.

Options exist to manipulate observations as follows:

1. Shift an observation in time
2. Delete an observation
3. Enter operationally required actions into observations.
4. Split a survey observation into two separate overlapping scans.
5. Shorten a survey observation.

While it is expected that the manual mode will not be frequently used during routine operations, it is sure to prove a valuable tool for dealing with ETLs for the in-orbit checkout period and for operational emergency situations.

1. Compile a list of observation candidates which can be scheduled in the gap.
2. Calculate the cost of scheduling each observation as the first in the gap.
3. Select the cheapest observation.
4. If the observation does not meet the maximum cost threshold limit go to step 9.
5. Flag the observation for scheduling.
6. Adjust the gap as if the observation were scheduled.
7. Compile a list (sub-set of 1) of observation candidates which can be scheduled in the remaining gap.
8. If the list is not empty go to step 2.
9. If the maximum cost threshold is not exceeded when the remaining gap is included, go to step 13. If all observation candidates in the original list are flagged for scheduling, go to step 14.
10. Implement backtracking by clearing the last observation flagged and selecting the next cheapest candidate at that stage.
11. If such a candidate exists, go to step 4.
12. Stop - the gap cannot be filled.
13. Schedule the flagged observations - the gap is successfully filled.
14. Schedule the flagged observations - the gap is partially filled.

Figure 18 Observation selection algorithm

8. CONCLUSIONS

The IRAS observation planning facility is designed to handle a vast amount of observations, originating at various sources. It will perform routine tasks to a great deal automatically, but it allows easy manual intervention.

An important aspect of the system is that it allows observers to use the satellite, without requiring detailed knowledge of the satellite subsystems.

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