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ABSTRACT

This article addresses the role of man in operating on orbit a large pointing system such as the IPS currently under development in Europe. After a brief introduction and project overview, the main areas for manned interaction are described followed by an illustration of the key operational features of the IPS and the crew involvement in each of these functions. The paper highlights the man-machine interfaces and concludes with an example description of a typical IPS operation.

INTRODUCTION

Europe is currently developing, for use on the NASA Space Shuttle, a large pointing system. This 3-axis Instrument Pointing System - IPS is developed by Dornier System for the European Space Agency ESA and forms part of the overall European Spacelab develop -ment programme.

The IPS, a facility type subsystem of Spacelab, is mounted onto a Spacelab pallet. It can accommodate a single or clusters of experiments with up to 3m diameter, with an experiment length limited only by the Orbiter payload bay and a total experiment weight of up to 7000 Kg (3000 Kg with the experiment clamping hardware produced during the IPS development phase).

IPS is designed to support 3 different types of pointing missions - stellar, solar and earth pointing - with a pointing accuracy in the arc-sec range. During the IPS development phase, all hardware and software necessary to support these 3 different mission types is produced and will be made available to NASA.

IPS DEVELOPMENT STATUS

The IPS - under development since 1976 - has undergone a major design change in 1981 due to significant requirements changes caused primarily by the increased Orbiter loads. As a consequence, the basic IPS structure including the gimbal axis drive units had to be redesigned. This redesign also resulted in a different drive unit arrangement and improved features for safety and for payload integration.

The critical design review is conducted in April of this year and delivery to the U.S. is scheduled for December 1983. The IPS will be flown for the first time on the SL-2 mission, currently scheduled for November 1984.

ROLE OF MAN FOR POINTING SYSTEM OPERATIONS

Manned operation and interaction with the pointing system has been an important design consideration from the early stages of the development phase onwards. The involvement of operations personnel from the NASA space centres, MSFC and JSC, in particular, from the astronaut office has resulted quite early in detailed definitions of how to operate IPS on orbit. Each operational function of the system has been analysed to determine which elements should be performed automated and which would benefit from manned intervention. This becomes obvious by the detailed contractual requirements laid down in the IPS Operational Flight Software Requirements Document (ref. 1).

Experiences - particularly on the Skylab with the Apollo Telescope Mount - have demonstrated that the mission success can be greatly enhanced by meaningful involvement of the crew. For the operation of the IPS, the crew is planned to be used primarily in three areas :

Experiment Set-up Operations. Experiment pointing operations can only be performed when the proper environment has been created which is determined mainly by Orbiter attitude, the IPS configuration and attitude and the experiment status itself. This environment is influenced by a rather complex scenario and set of mainly time dependent constraints such as experiment requirements, thermal condition, contamination, other experiment operations, etc. The crew is used to co-ordinate and set up this scenario leading up to the start of the experiment operations - a task very difficult to automate within reasonable resources. However, once started, the various IPS operating modes will execute automatically freeing the crew to concentrate on the experiment operations itself. For IPS, the crew will only be needed again for a new set-up i.e. to perform the sequencing of different preplanned pointing operations.

Corrective Actions and Unplanned Activities

The crew is used, in its' unique human capabilities, to recognise, assess and react to an unforeseen or unplanned event. This is of particular importance on the relatively short IPS/Shuttle missions of only nominal 7 day duration. As a consequence, the IPS system must provide the crew with sufficient cues and data to allow recognition and assessment of the situation and command capability to interact and manipulate the system accordingly:

Any correctable malfunction or misbehaviour of the system should be corrected immediately by the onboard crew without involvement of the ground controllers and complex (time consuming) assessment activities by mission control.

The crew should also be able to react immediately to unexpected developments in the scientific area and perform substantial rearrangements of preplanned activities.

Safety Operations. The IPS, when deployed, will penetrate the dynamic envelope of the Orbiter payload bay. This will constitute a serious safety hazard to the entire spacecraft if IPS cannot be securely stowed or separated from the vehicle in case the stowage fails. The crew will supervise the normal software supported stowage manoeuvre but can also, in cases of failures, perform each of the related steps individually to configure the system for safe Orbiter return. These consist of back-up stowage, contingency stowage, jettison of the payload or of the entire IPS and may require the crew to perform specific IPS extra vehicular activities (EVA) depending on the failure mode of the system.

The presence of the crew has allowed to design a relatively simple system which avoids automation in the area of safe stowage. It offers multiple back-ups by combining individual functions selectively, and involves the crew to overcome mechanical problems manually. An automated system would have been far more complex to achieve the same performance concerning safe stowage: the operator makes his decision on the real condition existing at the time of the event; the designer must preconceive all conditions which could exist and implement the resultant decisions into the system design.

IPS KEY SYSTEM FEATURES

Control Loops. The IPS pointing control is realized by a digitial control loop (fast loop). It generates corrective torques for each of the gimbal axis by comparing the actual inertial attitude derived from gyro measurements with the desired attitude. The fast loop is executing in an IPS dedicated processor, the Data Control Unit (DCU). It is powered, loaded with flight software and initialized by the crew during the IPS activation process. During normal pointing operations it does not require further crew attention.

An Optical Sensor Package (OSP) with 3 Fixed Head Star Trackers generates corrective signals via Kalman filtering, to compensate for attitude and drift errors of the fast loop (slow loop processing). The OSP can be configured premission to acquire either stars with all 3 trackers for stellar missions or the sun with the boresighted tracker and stars with the skewed sensors for solar missions. When the OSP is not tracking celestial targets, IPS is using the data of the last drift update and continues pointing with the fast loop only.

The OSP employs 3 dedicated micro-processors which are powered and initialized by the crew during the IPS activation procedure. During normal pointing operations, the OSP is only commanded implicitly when the crew commands IPS to perform specific functions (for example, initial star acquisition) which necessitate different operational modes of the tracker system.

For specific applications (experiment control option) it is possible, by crew command, to replace the signals of the boresighted tracker by experiment generated signals.

Desired Attitude Generation. All IPS pointing operations are performed by selecting premission defined objectives. An objective - identified by the crew via its' objective number - is a set of data driven by experiment requirements and stored on the Spacelab mass memory unit (MMU). Each objective contains the desired attitude in one of the 4 possible coordinate systems: aries mean true of date inertial -,solar ecliptic -,local vertical - and landmark track - coordinate system. These data are displayed to the crew for reference and internally transformed into the desired inertial attitude to be used by the IPS control loop. The attitude data can be modified by crew commands individually for each coordinate system axis.

The objective may also contain data about the celestial targets to be acquired by the OSP for the particular attitude. These data, established premission from a star catalogue, are invisible to the crew and can only be modified by ground controllers by changing the data on the MMU.

Included in each objective is a crew selectable experiment number. This allows to point the IPS line of sight (LOS) and up to 4 different experiments to the desired attitude. These experiments can in principle have any orientation relative to the IPS LOS. The IPS will perform a corrective attitude manoeuvre automatically when selecting the desired experiment number, according to the specific experiment orientation.

On Orbit Calibration. If experiment measurements allow to determine the real position of the experiment (for example output optimization) the orientation of the experiment relative to the IPS LOS can be updated by a crew command sequence (manual calibration).

Another method which provides for continuous calibration is also selectable by the operator. In this option (on Orbit Alignment Measurement System - OAMS option) an artificial star pattern generated by the experiment is mirrored into the boresighted star tracker. Any misalignment of this pattern with the predetermined position is used to produce offset attitude commands.

Offset Pointing. The desired attitude given by the selected objective can be modified by the crew by superimposing different offset-commands. These are experiment generated bias signals, (experiment command option), an IPS generated scan profile or a manually induced offset motion generated by the Orbiter provided manual pointing controller (MPC).

For the scan option, the scan profile data are normally premission determined and loaded from the MMU when selecting an objective. However, the crew may individually modify each of the scan parameters such as line length, line separation, rate, number of lines, number of frames and the roll orientation of the entire scan field. For the MPC, the crew can determine the maximum rate and select - at the MPC hardware - 3 rates for line of sight motion and 3 different rates for roll.

Axis Control. Although, normally, the position of IPS is determined by attitude commands, it is also possible for the operator to control each IPS gimbal axis individually. This will primarily be used to position IPS fixed relative to the Orbiter when performing Orbiter or other payload manoeuvres.

A specific command allows to immediately stop all motions of IPS relative to the Orbiter (gimbal hold command). This command is also automatically invoked when functions are commanded which should only be executed with no IPS relative motion.

Mechanism Control. The configuration of the IPS utilizes an inside-out gimbal system which results in large payload CG-offsets relative to the IPS centre of rotation. To prevent the payload and IPS from exerting eccentric loads during launch and landing, they are separated structurally from each other and attached to the Spacelab pallet independently. This is achieved by 3 different mechanisms.

The Payload Gimbal Separation Mechanism (PGSM) serves for separating the payload from or attaching the payload to the IPS. The Gimbal Latch Mechanism (GLM) serves to securely latch the IPS gimbal system to the pallet, whilst the Payload Clamp Mechanism (PCM) locks the IPS payload in place at 3 different locations.

Normally these mechanisms must always be operated in a specific sequence. A wrong sequence or operation at the wrong time could damage the hardware or even lead to a serious hazard to the entire spacecraft. However, to retain system flexibility in cases of contingencies, the crew has the capability to control each mechanism individually and independent of each other. To prevent crew mistakes, special safeguards are built into the system:

Each mechanism command must be armed by the crew before execution. Each mechanism control itself contains 2 internal inhibits. If one of these inhibits is removed (malfunction, erroneous command, etc.) the system automatically generates a visible and audible crew alert.

Collision Avoidance. The crew is not involved to prevent a collision between IPS and Spacelab or Orbiter structure. A mechanical device - a bumper ring - limits the operating cone of the IPS. It is adjustable between missions and designed for the maximum possible impact forces. A crew alert is generated when IPS is located close to the bumper, but the crew may elect to disregard the message and let IPS touch the bumper (for example, during a scan manoeuvre where only the predetermined scan field is cut off by the bumper location).

OPERATIONS MEDIA

Flight Software. The large number of complex functions which the IPS must perform in a fairly autonomous manner requires a significant amount of executable flight software. In addition to supporting the execution of the functions themselves, a sizeable portion of the on board software is devoted to handle the crew interface.

The IPS software is executing in the IPS DCU for fast loop processing and in the Spacelab Subsystem Computer (SSC) for all other functions. Because of the limited resources available to IPS within the SSC (22.5 K words of core) different Memory Configurations (MC) have to be utilized to operate the IPS. Each MC must be loaded by the crew from the Spacelab Mass Memory Unit (MMU); an automatic overlay which would configure the software independent of crew activities is not in accordance with the operating principles established for the Orbiter and Spacelab System operation.

For a typical stellar mission which intends to use all features offered by the IPS design, seven different MC's are required. These MC's range from supporting only a single crew commandable function - such as initial stellar acquisition and automatic OSP calibration - to supporting the entire IPS activation/deactivation activities with approximately 40 different crew commands.

Data Display System. All crew interfaces are provided via the standard Spacelab keyboard and Color Data Display Unit (DDU). The method employed is consistent throughout the entire Orbiter/Spacelab/Experiment system and uses Fixed Format Displays (FFD) and item number commands. The underlying principle of the FFD/item number concept is the following:

(a) All data to be displayed and all commands planned to be issued are preconceived and contained on the FFD at a predetermined fixed location.

(b) The FFD must be visible on the Data Display System currently in use by the operator; only then will commands listed on the respective FFD be accepted by the system.

All necessary information related to the command is contained on the display as fixed data. The command itself is represented for executed only by an "item number". Contiguous item numbers from 1 through N are assigned to each FFD. Each command is issued by a simple 3-keystroke command syntax:

ITEM — ITEM # — ENTER

To enter parameters, the syntax is slightly modified and includes data entries after the item number.

This system, which forces the operator to call up a display before issuing a command, prevents him to issue commands from memory and therefore reduces the probability of making a mistake. As such, the FFD serves as an instruction sheet for all keyboard commands available to him and as a listing of the related command numbers.

To operate IPS through a normal mission scenario only 2 FFD's are required: One display is dedicated to the activation and deactivation of IPS as well as the unstow and stow manoeuvres (see Fig.2). The other display is dedicated to the particular pointing operation itself (stellar, solar or earth mode), and includes all commandable options available to the operator (see Fig.3). Only for earth missions - as no earth sensors are part of the IPS system - a stellar or solar FFD must also be used when, for accuracy reasons, attitude updates using celestial targets are needed.

The system is augmented by 3 housekeeping displays dedicated to IPS thermal control, to the electrical system and to the IPS mechanisms. These FFD's however, are only needed in cases of malfunction or contingencies.

With this system, the crew will use, in principle, only one FFD to support the entire experiment operations during a stellar or solar mission. This display has to be called up for the IPS set-up before each experiment data taking. Thus the direct interaction of the crew with IPS is kept fairly simple and minimized to give sufficient time to concentrate on the experiment operation itself. As an example, on SL-2, where a cluster of 4 experiments is mounted to the IPS, a total of 13 operational and 5 housekeeping displays for these experiments will require crew attention.

Message Generation. As the IPS must operate most of the time unattended, i.e. without displaying permanently IPS data to the crew, it is of extreme importance that the IPS will automatically inform the crew if a malfunction or abnormal operation of the system has occurred. The IPS therefore contains a fairly elaborate error and tutorial message generation system.

Each generated message will be displayed immediately (in red) on a dedicated message line of each DDU accompanied by an aural alert. The message itself consists of a text string indicating the type of problem, the name of a FFD which should be consulted for more information or corrective action, and - if necessary - a number indicating the details of the cause for the message. These numbers will be contained in the crew checklists or cue-cards and need to be consulted by the crew for correct interpretation of the message.

It is obvious, that messages which require a clear and immediate crew reaction must be unique and will, therefore, consist of only the text with no or very few error numbers. As an example, the message "IPS NEAR LIMIT" warns the crew that the IPS is in danger of contacting the bumper (error number "1") or that the IPS roll axis has almost reached its maximum roll angle (error number "2") and will be stopped by a mechanical endstop device. The crew can in these cases immediately issue the command "gimbal hold" via a dedicated function key. On the other hand, the error message "IPS TEMP" can be followed by approximately 40 different error numbers indicating the out of limit condition for a particular temperature sensor. In such a case the thermal control housekeeping display would have to be consulted. On this FFD the respective parameter would immediately be discernable by the crew as it appears in overbright green.

To complement the system and in order to allow traceability when several messages occur at the same time, all messages are summarized in the Spacelab Fault Summary Page. It contains the last 10 error messages and the last 5 tutorial messages together with their time of occurrence.

The IPS currently generates 20 different message texts with approximately 150 different causes for these messages.

Control Panel. In case of failures of the elaborate software system due to loss of the subsystem computer, computer peripherals, main power, IPS processor etc. the IPS must still be safely stowed or separated from the vehicle. For these functions a contingency control panel located in the Orbiter aft flight deck is used (see Fig.4).

It is connected with dedicated IPS hardware which is powered by the Spacelab emergency power bus. It provides switches and indicators to control individually the motion of each IPS gimbal axis and the operation of each IPS mechanism. No interlocks or hardware sequences are built in - the operation relies upon proper sequence initiation by the crew.

TYPICAL OPERATION EXAMPLE

The following example illustrates the crew interventions and actions in performing a typical function of a stellar mission: objective of the operation is to select a new target and start a scan manoeuvre with attitude up-dates generated by th OSP. The stellar mode FFD IST is used for this operation (see Fig.3).

Crew loads objective from MMU (item 2, objective number).

> The objective and experiment number and the coordinates for the attitude appear in the desired column (DES); the desired attitude is also shown in the Orbiter fixed AZ-COEL system.
>
> Two crew alerts in overbright green could occur behind EXEC; a "LIM" to indicate that the desired attitude is outside the IPS pointing cone and or

a "SLEW" to indicate that a particular memory configuration is needed to execute the manoeuvre for acquiring the desired attitude.

Crew loads the SLEW MC (item 25) - if needed - and issues the EXEC command (item 7).

IPS moves towards the new attitude until the data in the DES and current (CUR) column are equal and the crew feedback behind EXEC indicating that a manoeuvre is in progress disappears.

Crew initiates the operational star acquisition/identification process by loading the function-dedicated IDOP memory configuration (item 27).

The process of the command execution can be observed in the OSP mode status fields which indicate the current operation of each star tracker (for example search, track, standby, search unsuccessful etc.) as well as in the respective fields behind SRT IDOP which identify the star triplet number which IPS currently tries to acquire and identify (up to 7 triplets can be defined for one objective).

After successful identification crew selects an optical hold memory configuration (item 28).

After successful MC load the feedbacks behind OH CTL will indicate the enable status of the Kalman filter and the subsequent start of OSP data processing.

Crew modifies the predetermined scan parameters in the DES column (item 8 through 13, parameter) if needed and starts the scan execution (item 14).

The IPS FFD is now no longer needed until the scan is terminated at the end of the scan programme and a new experiment set-up is required.

CONCLUSION

The IPS requires only little crew attention during normal pointing operations. The man machine interfaces allow easy operation of fairly complex tasks. For the majority of the time the crew can fully concentrate on the supervision of the experiment operations. Although all IPS operations will be extensively tested during the development phase it will still take actual flight experience to determine the optimum role of man in the operation of this large pointing system.

REFERENCES

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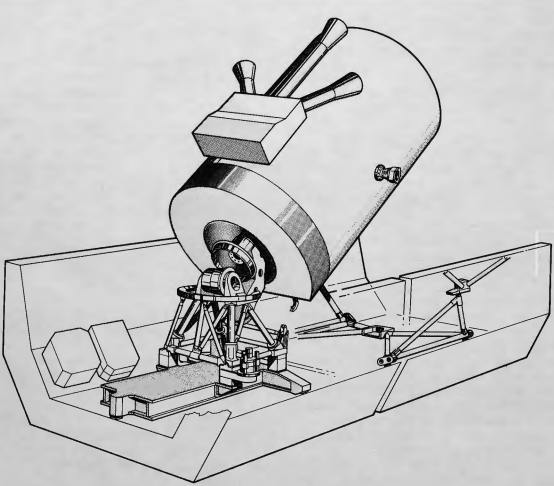
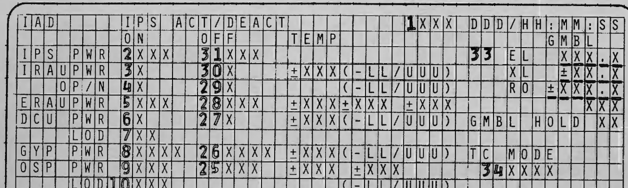


Fig. 1 IPS CONFIGURATION OVERVIEW



2 : YELLOW   □: FLASHING   *) ST FOR STELLAR

Fig. 2 IPS ACTIVATION DISPLAY - IAD

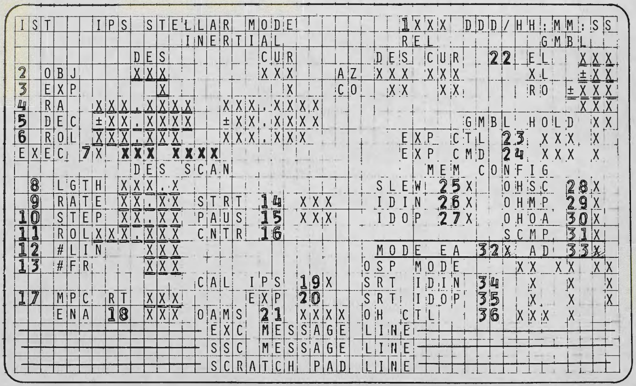


Fig. 3 IPS STELLAR MODE DISPLAY - IST

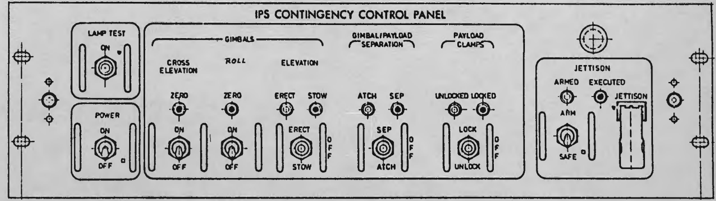


Fig. 4 IPS CONTINGENCY CONTROL PANEL