

**FLUID PHYSICS MODULE
UTILIZATION BROCHURE
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The Fluid Physics Module (FPM) is the first European multiuser facility for supporting fluid physics experiments onboard the manned orbiting laboratory Spacelab. At present, the engineering model is available for checking tests; the flight unit for the first Spacelab payload will be delivered within this year. Some modifications being still under consideration, this short brochure can only be an intermediate approach to clarify the FPM actual capabilities and to promote its utilization.

The arrangement of this brochure is as follows: first, as an introduction, the FPM is presented in the context of fluid physics experimental facilities in space; second, the basic design is introduced, followed by present performances (complemented with a data compilation added as appendix). Perhaps for the newcomer, the best way to proceed would be to read first the part on Experiments on the FPM, that comes afterwards. Finally a summary of the present FPM interfaces has been included.

1. THE FPM IN THE CONTEXT OF FLUID PHYSICS EXPERIMENTAL FACILITIES IN SPACE.

Two different philosophies are commonplace in designing experimental facilities for space research: 1), the instruments-dedicated approach (such as the USA's Fluids Experiment System) where the emphasis is put on multichannel data acquisition from an otherwise undefined test chamber (usually these instruments require little or no human intervention), and 2), the experiment-oriented approach, such as the FPM (mainly devoted to the floating-zone management) where permanent attendance of a carefully trained Payload Specialist is normally required.

The experimental facilities under development or in an advanced definition phase for Spacelab are:

Suitcase-type equipment

Autonomous, or requiring minor interfaces with Spacelab, they have the unique advantage of independent and last-minute integration allowances.

The Fluid Physics Module (FPM)

The only fluid physics multiuser facility for the first Spacelab, the FPM is a compact apparatus mainly designed to form and handle floating liquid zones, but with a much wider variety of experimental capabilities due to its modular conception (as the first utilization clearly shows).

Present status. The FPM has been developed and manufactured by FIAT Centro Ricerche on behalf of the Italian National Research Council under ESA coordination. The flight hardware consists of a bulk module (43kg, .45x.52x.61m) incorporated in the Materials Science Double Rack (MSDR), through which the FPM interfaces with Spacelab, plus some small appendages and tools stored apart. Besides, there is ground support equipment (mock-up and engineering models, test rigs, operation simulator, etc.) to help the user and the operators.

Future trends. An extension of the capabilities presently offered by the FPM is foreseen for future flights in order to incorporate other areas of research and to deepen in the present ones. This extension has a twofold aim: 1), to better adapt the FPM to Spacelab (avoiding the intermediate step of the MSDR), and 2), to improve its own performances by the insertion of new operating modes.

The Process Chamber (PC)

The PC is a large (double rack) facility-under study by ERNO on behalf of DFVLR, to carry on a great variety of fluid physics experiments, located in different chambers, with common diagnostic, instrumentation and support equipment. Chambers are tailored to conduct, very accurately, experiments such as floating zones, diffusion, Marangoni convection, corrosion, deposition of dispersion layers, cellular convection, capillarity in porous media, solidification fronts, and boiling.

The Drop Dynamics Module (DDM)

The DDM is a project already started in the early 70's by the Jet Propulsion Laboratory (California), of a double rack to be used as an integrated facility for the study of acoustically levitated drops (some centimeters in diameter) positioned at the center of the acoustic chamber (in a nodal region

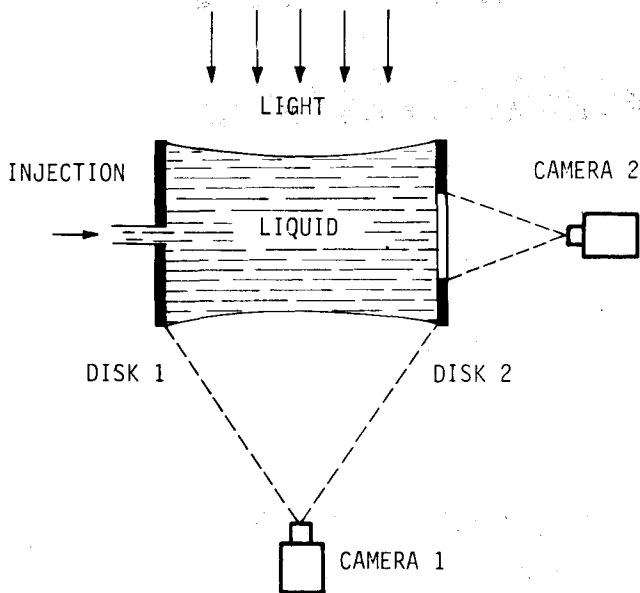


Fig. 1. Basic sketch of the FPM.

of the pressure field) and disturbed mechanically (rotation, vibration) and electrically. The control variables are: temperature, pressure, intensity of the electric field, and amplitude, frequency and phase of the acoustic field.

The Zero-Gravity Combustion Facility (UGCF)

This is a facility designed by NASA, where suitable contained gaseous, liquid or solid fuels can be burnt in a controlled atmosphere (composition and pressure). The instrumentation will range from pressure and temperature transducers to laser anemometry.

The Fluids Experiment System (FES)

The FES is a double rack facility under definition at MSFC (with TRW as prime contractor) aimed at providing a very complete variety of optical instruments (Schlieren, shadowgraph, interferometry and absorption measurements) for fluid-behavior recording under preselected temperature profiles.

2 THE FPM DESIGN.

The basic idea for the FPM is to provide a precision apparatus for establishing a liquid bridge between two parallel coaxial disks (sketched in Fig. 1) in a micro-gravitational environment, allowing for some disturbances to be applied to the liquid whose behavior is then studied. The liquid, contained in an interchangeable reservoir, is injected into the test section through the center of one of the end plates. Disk separation and liquid volume can be varied at will (within the stability limits), and several small disturbances applied to the liquid mass through the solid disks (rotation, vibration, heating, etc.).

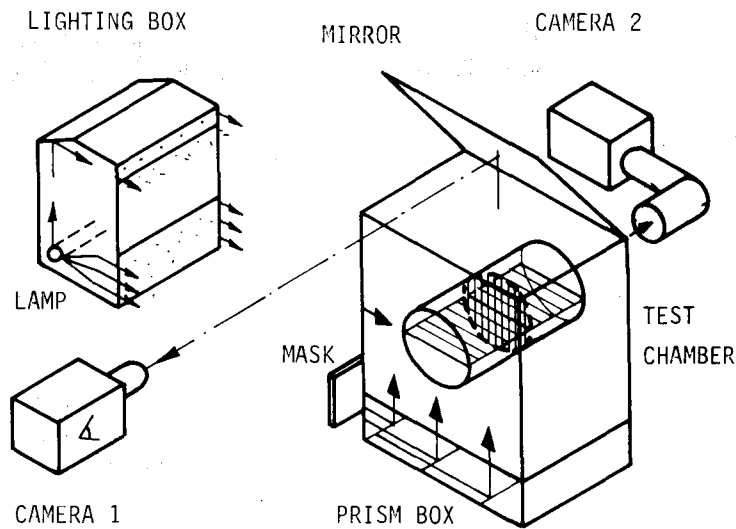


Fig. 2. Visualization system (a cylindrical liquid zone is shown).

Means are provided for photographically recording the liquid outer shape and the velocity field in its interior (using tracers).

The key-points for the definition of this facility have been: 1), to provide for "a liquid-bridge making apparatus", with special interest on cylindrical zones up to ten centimeters long (a direct coupling of injection and stretching has been kept); 2), to allow for independent control of the liquid volume in order to be able to attain any possible equilibrium shape; 3), to accept disks and liquids of different kinds according to the user requirements on size, shape, wetting and spreading characteristics, liquid viscosity, thermal expansion and so forth. In fact, this third point has been conclusive for adopting from the beginning a modular concept, with interchangeable disks and reservoirs, paving the way to the appendages approach that so widely extends the FPM capabilities. With this as a baseline, several fundamental fluid-physics problems can be investigated: natural and enhanced column stability, onset of Marangoni convection, drop coalescence, interfacial forces, etc. In addition, a certain number of controlled disturbances is made available to the user acting upon the liquid; these disturbances can be mechanical (rotation, vibration and disalignment), thermal (heating) and electrical (establishing a potential difference between the end disks). Furthermore, the inclusion of the photographic recording system as an integral part of the FPM was deemed absolutely necessary for reliability and logistic conditioning; the overall visualization system is shown in Fig. 2.

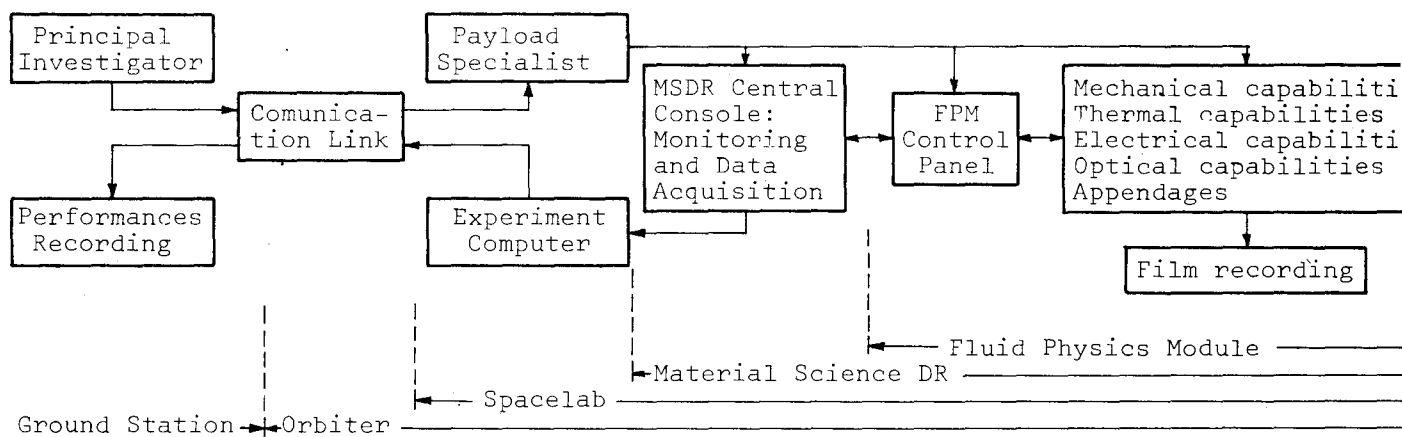


Fig. 3. Block diagram for operation of the FPM during the first flight.

On the whole, it is an integrated fluid-management experimental facility to be operated by one payload specialist trained in this area of research. The output of the mission will be a set of images and a record of the actual performances; the block diagram (for the first flight) is presented in Fig. 3.

3. PRESENT PERFORMANCES

In the following description no mention at all will be made of how the present performances have been achieved under the severe constraints imposed on the first Spacelab mission; rather, the user's point of view will be retained.

All the FPM performances stay centred in the two end disks (the handlers of the liquid). The FPM design provides several degrees of freedom such as linear and circular motions, temperature, electrical potential, etc., all of them related to the end plates. The FPM utilization consists of making appropriate use of the control variables by means of the operating modes offered.

Presently, the FPM can perform in a multiplicity of operating modes; Table 1 sums up

Table 1. Single operating modes

Mechanical capabilities
-Injection/stretching
-Disk 1 rotation
-Disk 2 rotation
-Synchronous start for rotation
-Disk 2 vibration
-Disk 2 lateral displacement
Thermal capabilities
-Disk 1 heating
Electrical capabilities
-Disk 1/disk 2 potential difference
Optical capabilities
-Filming (single frame and cine)

the single modes (any set of which can be operated at a time).

The variables that can be controlled as well as the available range, are compiled in the Appendix. It should be realised that although some bounds are difficult to change because it would involve major changes in the hardware, most of the limits could be easily varied (just by changing a resistor); they are included for definition purpose, and it does not represent a real limitation.

Visual access to the test chamber is provided through a small window in the front panel of the rack (in parallel with camera 1).

4. EXPERIMENTS ON THE FPM

For experimentation on space laboratories the constraints on cost and development time are so high that, aside from some small suit case-type experiment, it is not possible for a research team to provide for its own equipment, and the only way to proceed is by joining other research groups and, either to share already developed facilities, or to develop a new multiuser facility that more closely fits their needs. On the other hand, for an existing multiuser facility to be successful some information-diffusion policy must be adopted, serving as guide to the user-to-be in order to share costs (as well as science and have more flight opportunities).

Concerning the FPM utilization program, the prospect appears very promising. Although, at present, the parallel development of hardware and experiments for the first mission jeopardizes the panorama, it seems to evolve towards a permanent ground-support facility located at ESA's Technology Centre (ESTEC) and a number of flight units (maybe FPM' modified to incorporate adjoining research fields as combustion or biofluidmechanics). This FPM ground-support facility would serve as an advising and testing place to help the users interfacing with the FPM and to implement the future improvements required.

Table 2. Utilization Program of the FPM in SL-1 (1981)

Code Number (1-ES-)	326	327	328	329	330	331
Principal Investigator	H.Rodot	J.M.Haynes	L.G.Napolitano	J.E.Padday	J.P.B.Vreeburg	I.Da Riva
Institution	CNRS Meudon	Univ.Bristol	Univ.Napoli	Kodak.Res.Div.	NLR Amsterdam	Univ.Madrid
Country	France	U.Kingdom	Italy	U.Kingdom	Netherlands	Spain
Experiment	Oscillation damping of a liquid in natural levitation	Kinetics of spreading of liquids on solid	Free convection in low gravity	Interfacial forces in a low gravity field	Coupled motion of liquid-solid systems in zero gravity	Floating zone stability in zero gravity
Time (minutes)	55	130	120	145	60	100
Energy (kWh)	.08	.17	.25	.19	.11	.15
Crew involvement	This first mission requires one Payload Specialist in full time					
UTILIZATION SCHEME						
Mechanical modes						
-Filling/stretching	YES	YES	YES	YES		YES
-Disk 2 vibration	YES				YES	YES
-Disk 1 rotation			YES			YES
-Disk 2 rotation			YES		YES	YES
-Synchronous start for rotation			YES			YES
-Disk 2 lateral displacement						YES
Thermal mode						
-Disk 1 heating			YES			
Electrical mode						
-Disk 1 / disk 2 electrical potential			YES	YES		
Optical mode						
-Filming						
cinemas	1	1	1 and 2	1	1 and 2	1 and 2
frames	1000	2000	3500	200	9500	3000
Appendages						
-Standard disks			YES			YES
-Standard reservoirs	YES	YES	YES	YES		YES
-Special devices	YES	YES		YES	YES	

The FPM can accommodate a great diversity of experiments ranging from the cartridge type (liquid enclosed) to the free-floating drop (helped by some positioning means), but its performances are unique when dealing with floating liquid zones: equilibrium shapes and their stability, Marangoni convection, surface chemistry, capillary hysteresis and damping, free-shear layers, spreading, drop coalescence, and so forth.

Maybe the best way to summarize the present capabilities of the FPM is just by quoting its first utilization program, foreseen for Spacelab 1, where a good example of its many possibilities is shown, summing up the different operating modes required for the six experiments in this first mission (Table 2); further details can be found in the corresponding references.

5. PRESENT FPM INTERFACES

Mechanical

The FPM is presently to be located in the MSDR (together with some furnaces and other equipment) mounted on telescopic slides to allow for its withdrawal when full access is required during preparation of every experiment. During operation, noise level is kept down to $10^{-3}g$ by a soft-mounting support. Besides, a clamp mechanism will protect the FPM during launch and landing.

Power

Normal power requirements are about 150 W (100 W are for the photographic lamp); when heating is required, all the available power (272 W in this first mission) is used. The total allowance for the FPM is .9 kWh (1% of the overall Spacelab 1 resources).

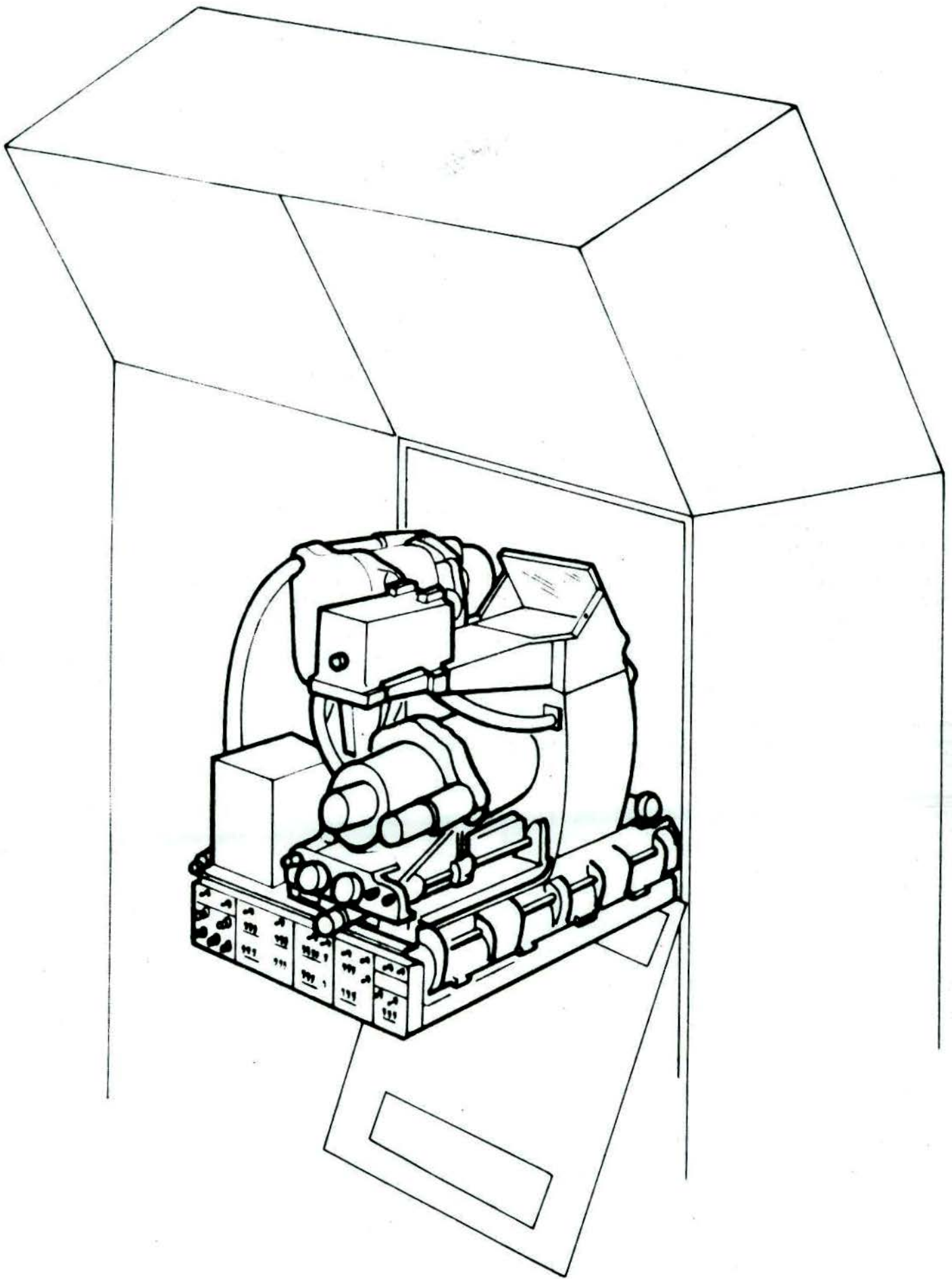


Fig. 4. Position of the FPM when withdrawn from the Materials Science Double Rack for experiment preparation and appendages mounting.

Data management

For the time being, data acquisition (other than image taking) is only considered as an accurate (and reliable) record of the actual FPM performances. These data can be monitored in the Central Console of the MSDR where the power and data acquisition commands are. The data sampled at the FPM feed a temporary buffer (located in the MSDR) with a 320 bits capacity that is sampled once every second. For normal Material Science applications, 320 b/s can be enough, but for fluid-behavior recording it might give rise to an undesirable handicap. These data are sent via the Experiment Computer directly to be stored on ground as sketched in Fig. 3 (but they could be used by the Principal Investigator to feed-back the Payload Specialist operation).

Data acquisition is performed synchronously with camera 1 at every frame. On the other hand, the whole information on FPM status and performances can be easily accommodated in a file of 20 words of 16 bits each (4 chosen for identification and 12 for data itself) so that, for less than 1 fr/sec, the whole file can be loaded on the buffer and sent to ground every second. However, if higher filming speeds are required (and indeed they are) some selection needs to be done (either reducing the amount of data being recorded at every frame, or by sampling every certain number of frames). For the first flight, a trade-off solution has been adopted and the more relevant parameters to be acquired are automatically selected according to a chosen sequence (still under development by MBB in Germany, who is responsible for the design of the MSDR Central Console).

Thermal

Overall thermal control of the FPM is achieved by means of the MSDR air-cooling loop. In addition, the FPM incorporates a sophisticated built-in air-loop for a more effective cooling of the test chamber when heating has been used for experimental purposes; this air loop is also intended to clean and dry the test chamber from droplets and spills produced when intentional or hazardous breakages of the liquid zone occur.

Optical

The FPM incorporates its own lighting and photographic systems. Outer shape visualization is provided by the change in refractive index and other optical peculiarities of surfaces of separation. Inner motion visualization is achieved by means of tracers (microballs) suspended in the liquid. On the other hand, permanent surveillance by the operator is normally required, and visual

access to the testing chamber is available through a small window in the front cover and a mirror (see Fig. 2). A TV monitor may be available for future missions if deemed appropriate. Up to now, there is no evidence at all of how troublesome the background illumination in Spacelab can be for the operator looking through the window.

Crewman

Human intervention is crucial for most basic fluid-physics experiments in Space (as well as on Earth). The allocated crewman time for the first FPM flight is about 1 hour (7% of the overall resources in Spacelab 1). Two training periods, one week each had been foreseen for familiarizing the crew with the FPM and its utilization program for this first mission, but the first one, already held in the United Kingdom in November 78 proved that more involvement was necessary if they were to substitute the Principal Investigator and not just to manipulate the set up. It is worth remembering that several years of research come into play and completely depend upon the mastery of the operator.

For Spacelab 1, the first 10 minutes of every experiment will be devoted to the last reading of instructions and comments; afterwards the step-by-step detailed description given by the Principal Investigator will be followed as far as reasonable; a provision for direct voice link would obviously contribute to the success of the experimentation.

Storage

Only the bulk of the FPM is located (in its present version) inside the MSDR (see Fig. 4) all the appendages (standard and special) and the tools, are located in storage compartments outside the MSDR. As mentioned above, a definition study has been started for an autonomous FPM in a single rack.

Safety

Safety regulations for Spacelab 1 have been extraordinarily tight, severely limiting the choice of liquids and reducing the range of some variables, but an ample relaxation is foreseen for future flights.

User

Means will be provided to facilitate the interface FPM-users by means of the Ground Support Facility in ESTEC. Besides, the six first experimenters, that have conceived and closely followed its development, have expressed their willingness to disseminate their knowledge of the FPM through direct assistance and advice to the new comers.

ACKNOWLEDGEMENT

The author wish to thank the present users of the FPM for their valuable support and comments, and particularly Mr. Huth for his encouragement and guidance that have given

rise to this work. He is also indebted to the FIAT team, that has contributed so much to the completion of this task through their permanent assistance.

APPENDIX: PRESENT PERFORMANCES OF THE FLUID PHYSICS MODULE

MECHANICAL CAPABILITIES

Control variables

Disks diameter : up to 100mm. Different shapes, sizes and materials
Disks separation : from 0 to 130 mm (step: .1mm)
Separation rate : from .1 to .999mm/sec (step: .001mm/sec)
Liquid : any kind (only silicon oils in the first flight). Interchangeable reservoir
Liquid volume : from 0 to 1300cc (step: .8cc)
Liquid injection : from .01 to 20cc/sec (step: .01cc/sec)
Disk 1 rotation speed : from ± 5 to ± 99.9 rpm (step: .1 rpm)
Disk 1 rotation ramp : 1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 100 rpm/sec
Disk 2 rotation speed : from ± 5 to ± 99.9 rpm (step: .1 rpm)
Disk 2 rotation ramp : 1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 100 rpm/sec
Disk 2 axial vibr. amplitude : from 0 to .5mm (manual)
Disk 2 axial vibr. frequency : from .1 to 2 Hz (step: .01 Hz)
Disk 2 frequency ramp : .1, 10 Hz/sec
Disk 2 lateral displacement : from 0 to 2mm (manual)

Operating modes

Coupled displacement of reservoir and feeding disk. Any filling/stretching ratio can be attained. Four variables must be selected: disk 1 final position and axial speed, and reservoir final position and speed
Disk 1 rotation. Two values must be selected: rotation speed and ramp
Disk 2 rotation. Two values must be selected: rotation speed and ramp
Synchronous start for rotation. Four values must be selected: disk 1 rotation speed and ramp and disk 2 rotation speed and ramp.
Disk 2 vibration. Three values must be selected: amplitude, frequency and frequency ramp
Disk 2 lateral displacement. Manual setting

THERMAL CAPABILITIES

Control variables

Disk 1 temperature: ambient, 60°C

Operating modes

Disk 1 heating (272W)

ELECTRICAL CAPABILITIES

Control variables

Disk 1 electrical potential referred to disk 2: 0, 100, -100V

Operating modes

Application of potential

OPTICAL CAPABILITIES

Control variables

Cameras operating mode: cine, brief exposure, time exposure
Cameras exposure time: for cine and brief exposure see the particular data from the camera supplier. For time exposure: .25, .5 sec
Cameras operating: 1, 1 and 2 (in this case, camera 2 is subsidiary of camera 1)
Cameras frame interval (in brief and time exposure mode): from .3 to 99.9 sec/frame (step: .1 sec/frame)
Cameras number of frames: from 1 to 999
Camera 1 type of film (15m cartridge)
Camera 2 type of film (15m cartridge)
Background illumination: filters
Cross-sectional lighting plane: sliding slit
Flow tracers

Operating modes

Cameras operating: 1) camera selection (1, or 1 and 2), 2) cameras operating mode, 3) exposure time, 4) frame interval, and 5) number of frames
The starting signal turns on the photographic lighting, shuts off the service lamp, activates the 1st frame flag, initiates the filming sequence with a certain delay to allow for steady illumination, shuts off the flag after the 1st frame is taken, stops the filming after the selected number of frames have been taken and turns off the photographic lighting, turning on the service lamp.

APPENDAGES

Standard appendages

Several disks (40, 60 and 100mm diameter) are available
Several reservoirs (liquids with or without tracers, different liquids) are available

Special appendages

Some first-mission users have developed special devices such as non-planar disks, several sealed liquid containers, a viewing aid, etc.
New users can also develop special appendages to be accommodated in the FPM. Care should be taken of interfaces: mechanical (dimensions and fittings), power, data management, thermal, optical, human involvement, storage, safety, etc.

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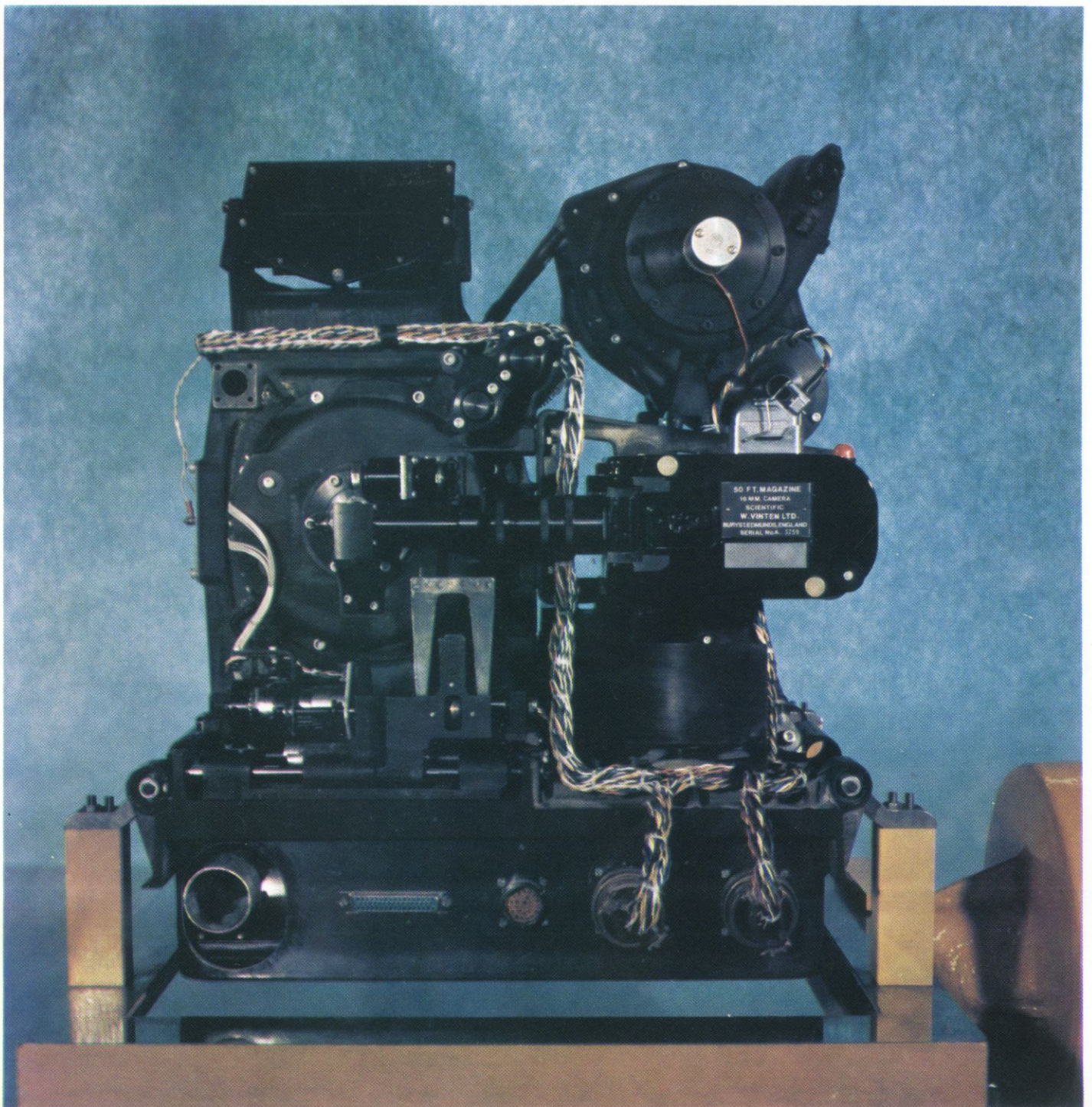
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NOTE

More information in experiments on the FPM can be found in the Replies to ESA A06 Announcement of Opportunity, July 1978.

A Long Term Report on Materials Science in Space, including very valuable guidance on Fluid Physics is being prepared by ESA.

Much of the Literature on the subject is to be found in the "3rd European Symposium on Materials Science in Space", April 1979.



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