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Final Report

NASA Contract NAS8-32805

**A Solar Magnetic and Velocity Field
Measurement System for Spacelab 2:
The Solar Optical Universal Polarimeter
(SOUP)**

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AND VELOCITY FIELD MEASUREMENT
SYSTEM FOR SPACELAB 2: THE SOLAR
OPTICAL UNIVERSAL POLARIMETER
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September, 1977 to January, 1991

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1.0 INTRODUCTION AND HISTORICAL SUMMARY

Historic solar observations were made with the Solar Optical Universal Polarimeter (SOUP) instrument which flew on the shuttle Spacelab 2 mission in August, 1985. SOUP is the only solar telescope either in space or on a balloon that has delivered long sequences of diffraction-limited (0.5 arcsecond resolution) images. This final report gives a summary of the long history of the program, a very brief outline of some of the scientific discoveries, and a more detailed description of the instrument and data analysis facilities, since these are not so readily available in the literature. However, the real accomplishments of the program are in the publications which its scientists and engineers have produced, which are listed in Appendix A.

The program began in 1987, with selection of a proposal for a scientific investigation of solar magnetic and velocity fields at high resolution, by development and flight of a filter magnetograph on the shuttle Spacelab 2 mission. The original selection letter (along with many others of historical interest) is included in Appendix B. The goals of the investigation were as follows:

- To measure magnetic and velocity fields in the solar atmosphere with spatial resolution greater than can be achieved from the ground and to deduce from these observations the small scale structure and evolution of these fields on the 10-20 minute time scale of solar granulation.
- To follow the evolution of solar magnetic structures over periods much longer than the 20-40 hour correlation lifetime of supergranules, in order to determine how the magnetic elements couple to the supergranule velocity patterns and by what mechanisms field diffusion and disappearance occur.
- To study with high temporal and spatial resolution the magnetic field changes associated with transient events such as flares, and to isolate and follow the birth of sunspots, pores, and ephemeral regions.
- To conduct joint observations of solar target regions with other flight solar instruments and with observatories on the ground, to learn the vertical structure of solar features from the photosphere to the corona.
- To help verify the performance of the Spacelab Instrument Pointing System (IPS) by measuring the pointing stability of the payload to very high frequencies.

The instrument designed and built to carry out these goals included a 30 cm Cassegrain telescope; fine guider and active mirror for image stabilization; white light film and TV cameras; birefringent filter, fully tunable over 5100-6600 Å; prefilters for selecting solar lines and for complete polarization analysis; 35 mm film camera and digital charge-injected device (CID) camera behind the filter; on-board computer and image processor; and an elaborate software system for interactive control of the experiment by the payload specialists on the shuttle. The filter was (and still is) the most sophisticated birefringent filter

ever made, with bandpasses of 50 to 125 mÅ, narrow enough to resolve spectrally the metal lines of the solar photosphere, for magnetic field and Doppler measurements.

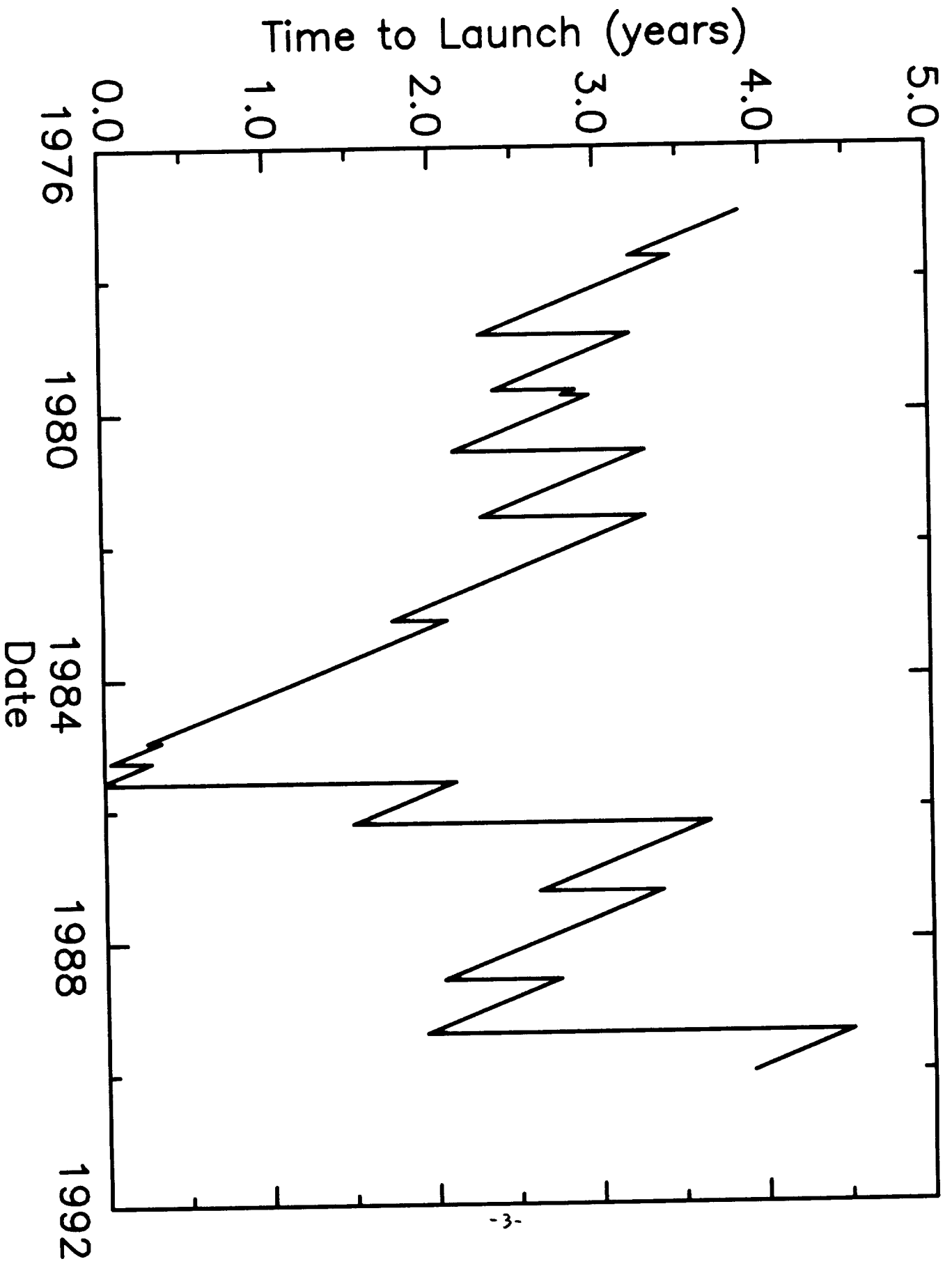
This ambitious package was built but only partially tested before its delivery for shuttle integration in 1983. In particular, testing by observing the sun from the ground was cut very short due to cost and schedule limitations. Severe problems for both the experiment developers and the mission managers during the development phase were caused by the ongoing but unpredictable delays of the early shuttle era. The plot shows the time to launch, according to the Spacelab 2 program schedule, versus calendar date throughout this period. From 1977 to 1983, the launch date was always 2.5 to 3.5 years away, meaning that delivery was usually only one to two years away. Thus, although the program was delayed for many years, development of the instrument was always pressing to meet an imminent delivery date. The development of the shuttle and Spacelab concurrently with the experiments ensured that groundrules and interfaces kept changing. In addition, there was great pressure to build low cost Spacelab experiments to verify the cost-effectiveness of shuttle access to space, and so the funding available did not cover the delays and changes of scope adequately. These forces combined with the peculiar schedule made the development phase of Spacelab 2 a rather stressful program for the engineers, scientists, and NASA officials alike.

SOUP flew on the Spacelab 2 shuttle mission (STS 51-F) from July 29 to August 6, 1985. It shared the solar observing time with 3 other experiments mounted on the IPS: CHASE, an EUV spectrometer from Appleton and Mullard Labs in the U.K.; HRTS, the UV telescope and spectrograph from Naval Research Labs; and SUSIM, an ultraviolet irradiance monitor, also from NRL. Because of a power failure for the first 6 days of the flight, SOUP only had orbits 100 - 116 on the eighth day of the mission for solar observing. The ground crews in the Payload Operations Control Center in Houston worked extremely hard to restore power to the instrument and then to recover as much scientific observing as possible.

The image stabilization and white light optical systems performed extremely well, and several hours of movies of a sunspot and active region were taken; a total of 6400 frames were obtained. Unfortunately, the tunable filter observations were largely unsuccessful: the film advance on the 35 mm camera failed due to an overheating problem, and the noise level in the CID pictures was very high. Some of the CID images were restored by computer processing, and they showed that the optical quality of the tunable filter system was also very good. The fine guider also produced very interesting data on the amount of jitter in the image before and after stabilization by the SOUP active mirror. Eventually these were used to evaluate IPS pointing and to show that the SOUP image stabilization worked to better than 0.01 arcseconds during quiescent periods.

A month after touchdown, the flight film was developed by Lou Gilliam, head of the photo lab at Sacramento Peak Observatory. Because of the high temperatures experienced during the flight and the long delay in getting the film out of the instrument, the density of the latent images had declined substantially and special care and extreme development were

SOUP Launch Date History



needed. The entire original negative was taken to a Hollywood film lab for copying and printing. The white light film contained the best solar movies ever obtained up to that time. The prints were full of details at the 0.5 arcsecond scale, which is the theoretical diffraction limit of the telescope. Therefore, the telescope and fine guider worked essentially perfectly. We compared SOUP images with the best ever taken on the ground, from the Pic du Midi Observatory in France. Although the best single frames from Pic du Midi had higher resolution, the SOUP movies were far more consistent in quality. For the first time, solar physicists were able to study the time dependence of granulation, pores, penumbral filaments, and faculae, free of image motion and atmospheric distortion and blurring.

During the Spacelab 2 flight, the instrument experienced some serious problems as mentioned above. These are discussed in more detail in a letter and additional comments in Appendix B. We since corrected all of the problems except the most serious, the fundamental non-redundant design of the power system, and the refurbished SOUP is now reassembled and operational in its Spacelab 2 configuration. The reflight version of SOUP was to have a completely new power system. The filter system has been extremely reliable and has completed millions of cycles of operation in the ground-based observing since it was refurbished.

After Spacelab 2, the solar experiments including SOUP were scheduled for a second shuttle flight on the Sunlab mission. Sunlab was placed on indefinite hold after the Challenger accident, and NASA informed us that it would explore alternative ways to accommodate the SOUP scientific investigation. After some study of other spaceflight opportunities (AstroSPAS and SAMEX), Sunlab was finally cancelled in November, 1987. The letter (see Appendix B) cited the upcoming flights of the High Resolution Solar Observatory (HRSO), successor to the Spacelab Solar Optical Telescope (SOT), as a major factor in the decision to cancel Sunlab.

In early 1987, we had begun studying the possibility of flying SOUP on a stratospheric balloon, following the tradition of solar balloon observations from the Stratoscope program of the late 1950's and German, Russian, and Japanese projects in the 1970's. In 1988, we proposed that balloon flight would be an ideal opportunity to use the existing SOUP instrument for a new investigation of active regions at very high resolution during the approaching solar maximum. This was accepted as part of the Max '91 Solar Balloon Program, and a definition phase was begun; eventually a new contract was opened for this, NAS8-38106. The figure also shows various launch dates which were proposed during the balloon era. However, in 1990 this flight opportunity was also cancelled due to lack of funds (see Appendix B), and the remaining effort was redirected to ground-based observing. In 1991, following the postponement of the Orbiting Solar Laboratory (OSL) mission (successor to HRSO), NASA expressed renewed interest in balloon flights of solar high resolution telescopes, and so SOUP or a descendent of it may fly again in this decade.

The SOUP universal tunable filter was refurbished after Spacelab 2 and tested exhaustively in air and thermal vacuum. In 1987, the filter and a 1024×1024 charge-coupled device (CCD) camera, the brassboard for the OSL Coordinated Instrument Package (CIP),

obtained outstanding scientific data in five weeks of observing at the Sacramento Peak Vacuum Tower Telescope of NSO. The same observing system ("SOUP/CIP breadboard") has observed at the Swedish Solar Observatory on La Palma, Canary Islands, every summer since 1988, and at the German Vacuum Tower Telescope on Tenerife since 1989. These runs have been extremely productive of high resolution data, and many scientific results have been published. Some real progress has been made on the first and third scientific objectives listed on page 1, but the second and fourth objectives (supergranulation and 3-D atmospheric structure) have still proven intractable with only ground-based observations.

The SOUP instrument proposed in 1976 was intended to serve as a scientific instrument in its own right and also as a support vector magnetograph/filtergraph for a wide range of missions on the Space Shuttle. The ability to fly as part of a number of missions dictated a compact size and modest weight. Time has its way of changing the wisdom of original plans, but in the case of SOUP there is little we would have changed in the instrument even if we could have foreseen the future in 1976. We proposed that on the first few balloon flights SOUP should fly in basically the same configuration flown on Spacelab 2, with only the replacement of the old vintage-1978 array camera by a modern CCD camera, the OSL CIP brassboard.

2.0 SCIENTIFIC ACCOMPLISHMENTS

The flight of SOUP on Spacelab 2 demonstrated the value of uninterrupted sequences of high resolution solar images. A combination of IPS constraints and the short duration of the sunlit portion of a low inclination orbit limited the duration of the SOUP data sequences to at most 45 minutes and usually less than 30 minutes. However, these sequences were the first ever taken of the solar surface that were not compromised by variations introduced by the Earth's atmosphere. The SOUP optics and image stabilization system operated perfectly in orbit with the result that the time sequences were also free of focus drift and image jitter.

Before the flight of SOUP the value of long sequences of high resolution images was recognized. However, only after the SOUP data was in hand did we really appreciate what could be done with such data. In particular the data showed how efficiently the 5 minute oscillations obscure the random dynamic events on the solar surface. It was seen that the granulation development, evolution, and motion in magnetic regions was fundamentally different than in the quiet sun after the 5 minute oscillations were removed. In the past there had been only weak statistical evidence for differences. The comprehensive paper on "Statistical Properties of Solar Granulation Derived from the SOUP Instrument on Spacelab 2" was called by its referee "a significant landmark in the long and tortuous history of the observation and interpretation of solar granulation."

SOUP data also demonstrated that proper motions of the local intensity pattern could be tracked by correlation techniques. This allowed measurements of horizontal flows with an accuracy that approaches 10 meters/second, a fundamentally new observable in solar physics. A large number of papers on horizontal solar flows resulted, and we have

since learned how to make these measurements from data obtained on the ground. This has spawned very fruitful ongoing research on the solar convection beneath the surface, turbulent power spectra, coronal heating, and the evolution of active regions.

The scientific accomplishments of the SOUP program are summarized in the reference list in Appendix A. This list includes results from the Spacelab 2 flight, instrument development and preflight solar research, and from the ground-based observing phase of the program. The list is only complete through the end of the contract in 1991; it continues to grow as existing data is studied and the instrument collects new data.

Over the last decade, a scientific team and an image processing laboratory have been assembled for managing and analysing the data-sets produced by SOUP on Spacelab 2 and by ground observing. Lockheed has provided nearly all the data analysis computing facilities, which are now the model for those at many other observatories, and support for research in digital image processing of movies. Sets of these data have been shared with several dozen scientists at other institutions, including approximately 10 graduate students. This activity is continuing today with other sources of funding from NASA, Lockheed, the NSF, and foreign collaborators; it represents a major portion of the solar high resolution research in progress in the world today.

3.0 SOUP INSTRUMENT

The SOUP instrument is designed to take high resolution images in narrow and white light on both film and solid-state array detectors. The scientific observations which it collects are summarized in Table 1. High resolution is achieved by an essentially diffraction-limited optical system and an image motion compensation and internal drift system to remove residual jitter and drift of the pointing system. The instrument consists of an optical assembly, the optical telescope and focal plane package which mount as a single unit, and electronic boxes which are mounted separately. The version of the instrument flown on Spacelab 2 was proposed for balloon flight with relatively few changes. The major differences proposed were that a CIP CCD camera replace the original CID camera and that modifications be made to the communications interfaces of the dedicated experiment processor (DEP) and the instrument to accommodate gondola avionics, to the image processor (IP) to handle the larger CCD images, and to the thermal and power systems which are required by the transition to the high altitude balloon environment. The properties of the instrument are summarized in Table 2.

Table 1: SOUP Observables

Observable	Method	Time	Rms Noise	Notes
Image Intensity Structure	CCD filtergram	2-4 s	0.17 %	1
	Film filtergram	2-4 s	2-5 %	2
Stokes Parameters Q, U, V	Filtergrams in RCP, LCP, L0, L45, L90	20 s	0.12 %	1
Longitudinal Magnetogram	Circular polarization	8 s	10 Gauss	1, 3
Magnetic Flux	Longitudinal mgram averaged over resolution element	8 s	4×10^{15} Mx	1, 3
Transverse Magnetogram	Linear polarization	12 s	100 Gauss	1, 3
Vector Magnetic Field	Stokes parameters at several wavelengths, fitting theoretical profiles	5 min	<5%	4
Magnetic Field Strength (Unresolved Structures)	5250/5247 V-Stokes ratio	16 s	TBD	
Doppler Velocity	Fourier method: fitting profile at 4 wavelengths	16 s	15 m/s	1,5
Transverse Velocity	Correlation tracking of continuum or line center	5 min	50 m/s	2
		60 min	15 m/s	
Line Center Intensity	Derived from Doppler fit	16 s	0.1 %	1,5

Notes:

1. Based on tunable filter and CCD performance at Sacramento Peak.
2. Based on SOUP performance during Spacelab 2.
3. Assuming SAMEX-type calibration for longitudinal and transverse magnetograms: ("The SAMEX Vector Magnetograph", NASA TM-4048, 1988, App. E).
4. Based on the exhaustive simulations by Lites and Skumanich ("Measurements of Solar Vector Magnetic Fields", NASA CP-2374, 1985, and private communication), who summarize their findings as follows: "One may recover the magnetic field strength and direction to good accuracy (5% or better) using filters with good to excellent spectral purity (FWHM < 100 mÅ) under the following conditions: (a) strong fields ($|B| > 1000$ Gauss); (b) good coverage of the line profile, i.e., at least two sampling points per instrumental resolution width; and (c) a signal-to-noise ratio in line with that expected from modern panoramic detectors." All of these characteristics are met by SOUP measurements.
5. Based on the velocity measurement technique devised for the SOI/MDI instrument on SOHO, which is linear and insensitive to line profile variations.

Table 2: Summary of SOUP Characteristics

TELESCOPE

Aperture	30 cm
Type	f/15 Cassegrain
Field of View	32 arcmin diameter
Wavefront Quality	0.06 waves rms at 6328 Å
Spatial Resolution	0.5 arcsec at 6000 Å
Wavelength Range	4800 - 20,000 Å

FINE GUIDER (jitter compensation)

Range	± 30 arcsec
Servo Sensor	4 photodiode limb sensors on movable mounts
Servo Actuators	Secondary mirror on PZT mounts
Servo Bandwidth	5 Hz (6 db), 200 Hz crossover
Residual Jitter	< 0.01 arcsec rms

COARSE POINTER (offset pointing and drift compensation)

Range	± 40 arcmin
Step Size	1 arcsec
Slew Rate	30 arcsec/s
Drift Compensation Rate (peak)	1 - 3 arcsec/s

WHITE LIGHT & TUNABLE FILTER FOCAL PLANES

Focal Length: white light	1800 cm (f/60)
tunable filter	2700 cm (f/90)
Field of View: white light	260 arcsec diameter
tunable filter	180 arcsec diameter
Wavelength Band	5100 - 6800 Å

Table 2: Summary of SOUP Characteristics, continued**TUNABLE FILTER**

Universal birefringent filter, alternate partial polarizer design	
Bandpass: 5200 Å	49 mÅ or 80 mÅ (selectable)
6500 Å	78 mÅ or 128 mÅ
Tuning Step Size: 5200 Å	2.2 mÅ
6500 Å	3.8 mÅ
Wavelength Reference	HeNe Laser (6328 Å)
Peak Transmission	30 % (in polarized light)
Average Tuning Time	0.5 sec
Polarization analyzers	RCP, LCP, 4 linear orientations
Spectral Prefilters	8 regions, 7 - 10 Å wide

TUNABLE FILTER SPECTRAL LINES

(Note: numbers in parentheses indicate narrow and wide bandpasses.)

Photosphere:

Continuum	Temperature, Horizontal Flows
Fe I 5250 (50, 82 mÅ)	Magnetic Field Strength
Fe I 5247 (50, 82 mÅ)	Magnetic Field Strength
Fe I 5576 (56, 92 mÅ)	Doppler Shifts (g=0)
Fe I 6302 (72, 118 mÅ)	Vector Magnetograms

Temperature Minimum:

Mg I 5173 (48, 79 mÅ)	Magnetograms & Dopplergrams
Na I 5896 (62, 103 mÅ)	Magnetograms & Dopplergrams

Chromosphere:

H α (78, 128 mÅ)	Morphology, Flows
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Chromosphere, Corona:

He I 5876 (60, 100 mÅ)	Morphology, Flares
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TUNABLE FILTER CID CAMERA (SPACELAB 2)

Sensor Type	GE CID-11B (Charge-Injected Device)
Image Format	248 x 244 pixels, 12 bits/pixel
Field-of-View	44 x 33 arcsec
Readout Time	0.5 sec
Full Well	2,000,000 electrons
Photometric accuracy (1 read)	1000:1

Table 2: Summary of SOUP Characteristics, continued**TUNABLE FILTER CCD CAMERA (SUNLAB & BALLOON)**

Sensor Type	TI 1024 x 1024 Virtual Phase CCD
Image Format	512 x 512 pixels, 12 bits/pixel
Field of View	72 x 72 or 143 x 143 arcsec (selectable)
Readout Time	0.6 sec
Full Well	200,000 electrons
Photometric accuracy (1 read)	300:1

FILM CAMERAS

Modified Photosonics, 35 mm stop action cine cameras

Film Load	6400 frames
Film Advance Time	1 sec
Frame Annotation	date, time, 12 numerals
Shutter Speeds: white light	0.02 - 5 sec
tunable filter	0.1 - 30 sec
Film Type: white light	Kodak SO-253
tunable filter	Kodak 2415
Field of View: white light	168 x 260 arcsec
tunable filter	110 x 188 arcsec

DEDICATED EXPERIMENT PROCESSOR (DEP)

Multi-task Operating System	Custom, in assembler language
Processor	Norden LSI/11 Emulator
Memory	4K ROM, 4K RAM, 16K core
Interfaces: Image Processor	16 bit parallel
Pointed Instrument Package	serial
Spacelab RAU or Balloon Gondola	serial
Test	RS-232

DIGITAL IMAGE PROCESSOR (IP)

Processor	2900 series ALU
Memory Organization	3 images: 512 x 512 x 17 bit
Operation Time (to add or subtract image pair (typical))	1 sec
Video Display Buffer (RS-170)	1 image: 256 x 256 x 8 bit
CCD Camera I/F	16 bit parallel, 900 Kpixels/sec
Image Data Telemetry Interface	High Rate Multiplexer or SCSI

3.1 Telescope Assembly

The SOUP telescope is a classical Cassegrain with a $f/3$ primary mirror of 33 cm diameter. The effective focal length of the telescope is $f/15$ and the effective aperture is 30 cm. It is a closed structure with a 33 cm front window and a 9 cm rear window. The focal plane of the telescope is 10 cm behind the rear window.

The front window has an all dielectric low pass filter coated on its front surface and a broadband anti-reflection (AR) coating on the second surface. The low pass filter reflects light below 4800 Å and transmits light above. Because the window is made of BK-7 all non-reflected light below 3300 Å and above 28000 Å is absorbed. The rear window is AR coated on both surfaces. The mirrors are coated with a multilayer dielectric coating on a silver film. The dielectric coatings on the mirrors and the front window serve to limit the flux on the mirrors in the region that silver absorbs. The overall coating design limits the heat absorption of the secondary to less than two watts.

In the flight of Spacelab 2 the coating system performed perfectly as verified by the thermal sensors on the primary and secondary mirrors and by the optical performance. Measurements made on the mirrors and on stored laboratory witness samples before and after the flight show no difference to within the precision in measurement. That is, the solar load had no effect on the flight mirrors. None of the mirror coatings have degraded significantly and we planned to re-fly the optics without recoating.

The primary and secondary optics are mounted in machined forged invar cells and are separated by a Serrurier truss made of invar tubes. The spider for the secondary is made of aluminum. The ratio of distance between the mounting points of the truss rods on the spider to the mounting points on the secondary mirror cell to that of the length of the rods is the ratio of thermal coefficients of expansion of invar to aluminum. Therefore, at any uniform temperature the separation of the secondary and primary remains constant.

The entire optical telescope including the limb sensor assembly is a complete optical, mechanical, and electrical package that is attached to the focal plane package with four bolts. Because of this construction it is simple to mate and demate the telescope for adjustments and tests purposes. This construction also makes it straightforward to test the response of the focal plane assembly by projecting test targets placed at the position of the telescope focal plane.

3.2 High Speed Image Stabilization System (Fine Guider)

The secondary mirror is mounted on three piezoelectric transducers (PZT) that allow the secondary to deflect the primary image formed by the telescope by about 30 arcseconds in any direction for 400 volts of applied voltage. Control of the secondary is determined by limb sensors in the telescope focal plane. These sensors generate an error signal for the servo drive. The cross over frequency of the servo drive system is 200 hz and the servo gain is 57 db, which reduces a disturbance by a factor of 600. The servo drive electronics

insure that the secondary tilts about a fixed vertex, so that displacement signals do not introduce defocus.

The hole in the primary of the telescope is sufficiently large that the telescope can be pointed to any position on the disk. The limb sensors are mounted on movable slides, so that the image can be stabilized at any solar position. The edge of the sun is sampled by pairs of small prisms spaced by 8 arcminutes in image space. Thus, even at the limb the image stabilization system can operate without occulting the image. There are four limb sensor assemblies each of which has two photodetectors. The DEP software can allow the servo control system to operate using only a pair of sensors on orthogonal axis, so the image motion sensor is highly redundant.

In quiescent operation of the IPS, the image stabilization system had rms pointing jitter of 0.003 arcsecond in each axis. The maximum deflection of the stabilized image was 0.02 arcsecond during a shuttle thruster firing, which deflected the IPS by 16 arcseconds.

3.3 Mispointing and Drift Compensation System (Coarse Pointer)

The SOUP optical system assembly is carried on a kinematic mount, which consists of six stainless steel tubes, "legs", with ball end fittings. Each mounting leg only constraints the distance between the mounting plate and the optical assembly. Changes in the length of the tubes, the optical assembly, or the mounting plate change the position of the package, but do not stress it. To correct for misalignments of up to ± 40 arcminutes in altitude and elevation, two of the rod end connections are movable by computer controlled stepping motors.

Control of slow drifts of up to 1 arcsecond/second of time can be corrected by the legs. The SOUP DEP monitors the voltages applied to the secondary mirror PZT's and commands the legs to keep the voltages near zero on average. The drift control system worked perfectly on the Spacelab 2 flight, and the correctable drift rate could be increased to 3 arcseconds/second, if required.

3.4 Focal Plane Package

The majority of the light entering the focal plane package is reflected upwards and out of the system. The light entering a five arcminute circular field on the optical axis is divided 95:5 to the narrow band tunable filter and the white light system, respectively.

3.4.1 White Light System

The optical system is quite simple with a single movable $\times 4$ reimaging lens. The final focal length is 1800 cm and the image scale is 87 microns/arcsecond. The images of the white light system are collected on a modified Photosonics 35 mm movie camera with a 400 foot, 6400 exposure, magazine. The 18 \times 24 mm film frame records an annotation line with time and image parameters, and has a field of 168 \times 260 arcseconds.

A beam splitter directs part of the light to a compact solid state video camera. The video from this camera is high pass filtered to generate a focus signal which the DEP uses to focus the video and film camera by moving the reimaging lens. We can downlink the video to provide a realtime image to verify the action of the autofocus and image stabilization systems. The autofocus can also be disabled, so that the focus can be commanded from the ground.

3.4.2 Tunable Filter System

The tunable filter path has two lenses: the first, which is movable, collimates the primary image and reimages the entrance pupil at approximately its focal length. The second lens reimages the primary image on the detector planes and also collimates the image of the entrance pupil. Together the pair form a $\times 6$ magnifier and produce a telecentric beam for the filter system.

Behind the first lens is a pair of mechanically identical filter wheels. The first contains acromatic waveplates for polarization analysis, while the second contains a set of 8 blocking filters which select the spectral ranges of the narrow band filter. The blocking filter wheel is temperature controlled to 0.5°C . Table 2 lists the contents of these wheels. The front window of the polarization analyser contains a waveplate to correct for the slight retardation of the beam splitter.

Spectral isolation is obtained with a 35 mm clear aperture, wide field, birefringent filter. The element lengths of the filter have been chosen to minimize the transmission side lobes and at the same time maximize transmission. By rotating an internal waveplate by DEP command, the filter bandpass can be increased by a factor of two for faster exposures and reduced sidelobe level. The filter is tuned by nine motors, which rotate waveplates or polarizers between wide field calcite elements. The crystals themselves do not rotate. Because only light weight components are moved during tuning the filter can go from any wavelength in any of the spectral bands to any other wavelength in less than one second. Tuning from one position in a spectral band to another position is accomplished in less time.

Wavelength stabilization is maintained by comparison with a He-Ne gas laser which is a part of the filter assembly. By opening the laser shutter, light at 6328 \AA is inserted into the filter. The filter can "lock on" the Ne line by scanning each tuning element in sequence through its complete range, which requires a 90° rotation of the tuning elements. The tuning positions which optimize the transmission of the laser light places the filter at the laser wavelength. The filter also contains a set of temperature sensors that are in near contact with the calcite crystals. Using the temperature of the crystals and the position of the reference laser line a computer program calculates the proper position of the tuning elements for any desired wavelength. Calibration takes about a minute and is only required occasionally.

Optically, the present tunable filter is identical to that used on the Spacelab 2 mission.

Several major mechanical improvements have been made. New motors and mechanical couplings have been installed, after life-testing a prototype for many million cycles. We have also added a small spring external to the expansion bellows, which allows for the expansion and contraction of the internal index matching fluids and the replacement of the shaft coupling on the motors. The spring insures that the internal fluid pressure never falls below 5 psi. This is sufficient to prevent the formation of bubbles within the optical cavity, as occurred on the Spacelab 2 mission. These mechanical changes have been proven in intensive lab testing in air and vacuum and in our observing runs at Sacramento Peak and the Canary Island observatories.

The tunable filter system has two optically identical image planes. One has a film camera identical to that in the white light system, while the other has an array camera. Exposures can be taken in either camera along or sequentially in both cameras, with a total cycle time of about 4 seconds. The film camera is exposed and film is advanced after the array readout is completed to avoid electrical interference. The final focal length is 2700 cm and the image scale is 131 microns/arcsecond. The Spacelab 2 instrument used a vintage 1978 CID camera designed by Dick Aikens of Photometrics; the balloon version proposed to use the brassboard CCD camera built by the OSL project at LPARL. Table 2 summarizes the two versions of cameras.

The CID/CCD signal is high-pass filtered in the onboard image processor to generate a focus signal for the tunable filter focal planes. An autofocus routine in the DEP is used to optimize focus by moving the collimating lens. The focus can also be commanded from the ground if necessary. The tunable filter and white light focus systems are independent.

3.5 Dedicated Experiment Processor (DEP) and Image Processor (VP)

On Spacelab 2 SOUP the majority of the power consuming electronics were in a separately mounted box, which contained the DEP, the VP, and their interface electronics to the Spacelab and power supplies. These computer systems, both hardware and software, functioned essentially perfectly during the Spacelab 2 mission. Balloon SOUP was to have three separate boxes to minimize the modification to the original electronics box and to provide more flexibility in counter balancing the optical assembly.

The DEP is a Norden emulation of a PDP 11/23, with a custom operating system and control program stored in ROM and non-volatile (magnetic core) RAM. Software is developed in a separate PDP 11/23 and downloaded into the DEP.

The DEP is the experiment manager and operator. It stores and commands the execution of the observing sequences, which are loaded before flight. Initial deployment of the instrument and selection of the observing sequences is done by command from the ground. Long series of observing sequences can also be run from a stored timeline. The DEP memory contains a larger set of such sequences than would normally be possible to carry out. The DEP runs the tunable filter, the autofocus procedures, the offset pointing, and serial communications between the ground control center and the experiment.

Spacelab 2 SOUP carried a very sophisticated image processor described in Table 2. Its functions included real-time corrections for gain and dark current; image arithmetic to make Doppler and magnetograms; buffering image data for downlink; video display of raw and processed data; and computation of image intensity and sharpness for autofocus of the TF system.

4.0 DATA ANALYSIS CAPABILITIES

The SOUP mission on Spacelab 2 produced 6000 frames of good data on film. We have digitized most of this film using the CIP CCD camera; once this has been done, film and CCD image processing are essentially identical. In full operation the ground-based filtergraph system collects data at a rate limited by the transfer rate to the data storage device. At the Canary Island Observatories, this was about one 512×512 array every 2.3 seconds.

From the beginning of the design of the SOUP instrument we have been concerned about handling large data sets. Our major data product is time series of digital images, and a flexible and convenient method of viewing is especially important. We have developed some very effective techniques for producing and viewing these as movies over the last several years. We generate processed video images on a VAX computer which are recorded in NTSC format on an analog video laser disk (which can record and display images one frame at a time as opposed to VCR's). The recorded disks can then be played on a low cost computer controlled commercial analog disk player and displayed on any normal (NTSC) video monitor. A small PC commands the disk player via a movie program called "Player". Player has various functions that allow "movies", defined segments of the disk, to be played at a wide range of rates in forward and reverse. Single images can also be displayed and pairs can be blinked. Control can be interactive or via command files which allow the creation of elaborate canned productions.

Our data processing and quantitative analysis are done using extensive interactive and batch software packages we have developed. Most of the interactive analysis and some of the batch processing uses ANA, an interactive image processing language. ANA can handle 1024×1024 images (and larger) and is used for flat field and gain corrections, image extractions, general image arithmetic and logic (e.g., creation of Dopplergrams, longitudinal and transverse magnetograms), Fourier filtering, and image and graphics display. It is also used to display and record our movie images. The basic processing steps of dark current, flat field, and flaw corrections as well as videodisk recording in quick-look format are now done for all frames in a sequence in one batch job.

Other major software capabilities include packages for image registration, de-stretching of images distorted by the earth's atmosphere, and local correlation tracking. The latter allows the generation of maps of the horizontal velocity in an image sequence. We have also pioneered the application of 3-D Fourier filtering techniques to solar movies. This software uses the ANA package and allows us, for example, to remove the effects of f and

p mode oscillations from time series of images or to isolate these oscillations in another time series.

The SOUP program has made use of all of the processing and analysis software developed for the Spacelab 2 flight, the CIP program, and the Lockheed ground-based observing program. Nearly all of the computer systems have been provided out of Lockheed funds. Also, Lockheed has been supporting image processing and movie generation software development at a level of 2 man years per year, much of which is applicable to this solar data analysis. Our software has been shared with many other solar observatories and is available to anyone willing visit our laboratory and spend some time analyzing data to learn how to use it.

5.0 ACKNOWLEDGEMENTS

The first Principal Investigator and designer of SOUP was Alan Title. After the Spacelab 2 flight, he chose to devote full time to the SOT-HRSO-OSL project, and so the Spacelab 2 project scientist, Ted Tarbell, became PI for the Sunlab and balloon phases. LPARL co-investigators at various phases also included Loren Acton, Steve Schoolman, Bob Smithson, Tom Pope, Harry Ramsey, Richard Shine, Ken Topka, Aad van Ballegooijen, and Jake Wolfson. Co-investigators at other institutions included George Simon, Pete Worden, and Steve Keil at Air Force Geophysics Lab at Sacramento Peak Observatory; Jack Harvey, Bill Livingston, John Leibacher, and Bob Milkey at National Solar Observatory in Tucson; and Ron Moore at Marshall Space Flight Center.

During the Spacelab 2 and Sunlab phases, the SOUP project was managed with great dedication and skill by Mike Finch, who also worked long hours on all aspects of the engineering of this complex experiment. He left in 1988 to manage the Solar-A Soft X-Ray Telescope project in our laboratory. The balloon SOUP project at LPARL was ably headed by Chuck Gilbreth.

The SOUP engineering team includes software and hardware specialists who have been familiar with the instrument for more than a decade. Special thanks go to: Harry Ramsey, for masterful fabrication of the tunable filter optical elements; Ralph Reeves, for mechanical design and construction of the tunable filter and much of the rest of instrument; Gary Kelley, the "SOUP starter," for electronics and endless testing of the instrument; Roger Rehse, for the DEP software and similar endless testing; Russ Lindgren, for all phases of design, construction, and programming of the VP; Dexter Duncan, for much of the electronic design; Bill Rosenberg, for testing of the tunable filter; Tom Pope, for assembly and test of the superb telescope and optics; and Ron Wallace, for thermal design and testing. The group also included "newcomers" on the SOT/HRSO/OSL team who worked on SOUP as well part-time over a period of 5 to 8 years: Mike Levay, Tom Fitzmorris, Darrel Torgerson, Chris Edwards, Mike Morrill, Kathy Wong, Noah Katz, Dave Akin, and Tom Cruz. In the data analysis and scientific research phases, outstanding support was provided by Stuart Ferguson, Zoe Frank, and Kermit Smith, in addition to many of the

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Obviously, we owe a large debt to the crew of Spacelab 2, especially the Payload Specialists Loren Acton, John-David Bartoe, Diane Prinz, and George Simon; and Mission Specialists Karl Henize and Tony England. Even more important than the flight operations were their contributions over the years in helping the experimenters understand and cope with the arcane ways of the NASA shuttle establishment.

Many NASA personnel and contractors worked just as hard as the exxperimenters to make Spacelab 2 a scientific success. Among the hundreds we encountered, a few outstanding contributors were: mission manager Roy Lester; operations manager Axel Roth; mission scientist Gene Urban; instrument manager Bob Harwell; integration manager Jim Moore; mission planner Becky Bray; crew trainer Arrah Sue Simpson; operations controller Fred Applegate; and NOAA solar forecasters Dave Speich and Jesse Smith.

Appendix A: SOUP Publication List

SOUP Publications List

Publication of Spacelab 2 Results

Papers

Simon, G. W., Title, A. M., Weiss, N. O., "Modeling Mesogranules and Exploders of the Solar Surface", *Astrophysical Journal*, **335**, 775, 1991.

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Topka, K., Ferguson, S., Frank, Z., Shine, R., Tarbell, T., Title, A., Wolfson, J., Scharmer, G., Brandt, P., "Observations of Granulation in Quiet and Magnetic Sun from the Swedish Solar Observatory on La Palma", *B.A.A.S.*, **20**, 1010, 1988.

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Appendix B: Letters of Historical Interest



National Aeronautics and
Space Administration

Washington, D C.
20546

AUG 4 1977

Ready to Attach

ST

Dr. A. M. Title
Lockheed Palo Alto Research
Laboratory
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Title:

I am pleased to inform you that your proposed investigation (see reference) which was submitted in response to AO-OSS-2-76 has been selected for a four to six month definition phase study for the Spacelab 2 mission.

At the conclusion of the study, the Spacelab Payload Program Office will determine whether the resources required for the instruments under study are consistent with available Spacelab resources. It should be clearly understood that some investigations selected for study may not fly on Spacelab 2 due to Spacelab or financial resource limitations.

As indicated in the Announcement of Opportunity, apart from scientific objectives, the second Spacelab flight is primarily an engineering flight intended to test the Spacelab systems and their interfaces with the Orbiter in addition to other verification objectives. Both the first Spacelab mission and this flight are also being used by NASA as a means of developing new, more cost effective programmatic methods of space research. To this end, the Agency does not plan to implement the customary high confidence, extensively documented program although interfaces will be clearly defined and rigidly controlled. The responsibility for instrument development will be delegated to the Principal Investigator. Details of how the program will be implemented will be conveyed to you by the Project Office during the definition phase. In general, the Spacelab 2 program, as well as all future Spacelab programs, will be implemented in a low cost manner. Each investigation and its associated instrumentation will be carefully evaluated in terms of interfaces, operations, future use, etc. to determine the most cost effective way it should be developed and conducted. It should be clearly understood that investigations which exceed their cost estimates are subject to cancellation or reconsideration for flight on later missions.

The Spacelab 2 mission management responsibility has been assigned to the Office of Space Science, Solar Terrestrial Programs Division, under the direction of Dr. Harold Glaser.

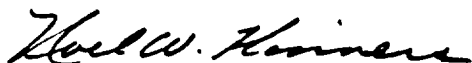
Project management has been assigned to the Marshall Space Flight Center (MSFC) Spacelab Payloads Project Office (SPPO). Dr. Eugene Urban of MSFC has been designated the Mission Scientist. He will be contacting the chosen investigators in the near future for the purpose of organizing an Investigators Working Group (IWG) which will help guide the development of the payload for the Spacelab 2 mission.

Please confirm your willingness to participate in contract negotiations for this definition study by writing to:

Dr. Jeffrey D. Rosendhal
Program Scientist, Spacelab 2
Code SAA, NASA Headquarters
Washington, D.C. 20546
(202-755-3687)

I would appreciate your conveying this information to the other members of your team.

Sincerely,



Noel W. Hinners
Associate Administrator
for Space Science

Reference: "A Solar Magnetic and Velocity Field
Measurement System"



National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of EZ-7

JUN 13 1983

Dr. Alan M. Title
S2-10 Solar Physics
Lockheed Research Laboratories
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Title:

The Solar Physics Office at NASA Headquarters has recently had several discussions with members of the Spacelab Flight Division on the possibility of reflighting the solar physics experiments from Spacelab 2 on another Shuttle flight, about a year after Spacelab 2. The scenario which we are currently looking at would involve reflight of only the solar experiments from Spacelab 2; we feel it would be advantageous for us if the rest of the payload bay were used to launch geosynchronous satellites, so that the large majority of the mission timeline could be dedicated to the solar physics objectives.

In preparing the case for the advocacy of this solar Spacelab 2 reflight, we would like several pieces of information from you as an experiment PI. In the science area, I would like to request that you send me a brief science rationale for a reflight, from the point of view of your investigation. An informal letter-style statement of about four pages would be sufficient. You should emphasize the new science that an SL-2 reflight will do beyond what you expect from the first SL-2 mission. I feel that discussion of ways in which an SL-2 reflight will extend, enhance and build upon the results of the first SL-2 flight is appropriate. Please try to include some specific examples of science you would plan to do on a reflight, rather than to just make general statements. If there are any wholly new experiments which for some reason cannot be done on SL-2, but could be done on a reflight please describe them. I may be called upon to create both written and oral summaries of the science rationale for a solar SL-2 reflight, so you might keep in mind possible graphics I could use.

The programmatic and integration aspects of this SL-2 reflight mission will be studied by the Spacelab Flight Division Program



25th Anniversary
1958-1983

office and by the SL-2 project, in the person of Roy Lester. Roy should be getting in touch with you soon to discuss strategies for implementation of the SL-2 reflight. In planning for a reflight, I strongly encourage you to try to minimize the amount of hands-on work that you would have to do on your instrument between flights. One major objective of this SL-2 reflight is to prove that a rapid, low-cost reflight of a Spacelab experiment package is possible, and any deintegration of the package or refurbishment of instruments between flights hinders this objective. Our ability to present a convincing case on how we plan to minimize cost and schedule will be an important factor in whether this solar SL-2 reflight is actually approved.

For many reasons which I am sure you can appreciate, the Solar Physics Office would like to have a large Guest Investigator program for the SL-2 reflight mission. I believe that as much as 60% of the observing time could optimally be devoted to GI's, although of course I realize that many investigations can overlap in their allocations of observing time and/or data. In your science rationale statement you may wish to include the potential importance of Guest Investigators. Otherwise, I would like you to give me your opinion on the optimal size and management aspects of a Guest Investigator program for the SL-2 reflight.

Thank you in advance for any assistance you can give. I believe the recent delays in the Solar Optical Telescope program have increased both the importance and the likelihood of approval of an SL-2 reflight, and I would like to present the best possible case for this mission.

Sincerely,



Eric Chipman
Program Scientist
Solar & Heliospheric Physics

cc: EZ-7/Pellerin
EZ-7/Opp
EZ-7/Weiler
EM-8/Sander
EM-8/Reeves
EM-8/Fleischman

Lockheed Missiles & Space Company, Inc.

Research and Development
3251 Hanover Street, Palo Alto, California 94304

December 6, 1985

Dr. Vernon Jones
Code EZ
NASA Headquarters
Washington, D.C. 20548

Dear Dr. Jones:

At the Spacelab 2 Science Meeting on 14 November, 1985, you asked for a letter discussing the optimum date for a second flight from a "purely scientific" point of view. It is impossible for me to discuss the scientific aspects of different flight dates separate from programmatic issues. The programmatic issues are, of course, budgets, schedules, and dates on which budget and schedule decisions are announced. I can discuss the impacts of a few different assumptions regarding launch delays and funding increases.

The SPAL proposal we submitted for a September, 1987, launch covered repair and refurbishment of the SOUP instruments with no improvements (from a scientific point-of-view) over the original design. The scientific program is basically that of Spacelab 2, with some straightforward extensions based on the data already obtained. We can meet this schedule and are willing to fly again on these terms. Any launch delay up to six months would not change our plans significantly: the extra time would simply be used for additional ground testing before delivery.

If a launch delay greater than six months were selected, then a more interesting possibility arises. The SOUP instrument contains a digital array camera for making magnetic and velocity measurements with a 2 dimensional field-of-view. The present CID camera was chosen in 1977 and represents a moderate cost, low-risk device of that era. Great advances in the state-of-the-art since then have made this camera obsolete (GE stopped making the devices several years ago). In our lab, we are using a modern CCD camera (a Solar Optical Telescope breadboard device) with four times the field-of-view, lower noise levels, faster readout and much greater sensitivity and uniformity. If a CCD camera of the SOT design were installed in SOUP in place of the CID, the scientific productivity would be dramatically increased.

We did not include a camera change in our SPAL proposal simply because the tight schedule before delivery of the instrument did not permit it. If this schedule is extended by more than 6 months and if additional funding (beyond the usual cost of a delay) is available, then we can improve the instrument in this way. However, if the

additional funding for a stretchout is only sufficient to maintain a minimal SOUP team, or if the delay is not announced early enough, then we cannot make the change and we consider such a delay very undesirable.


Alan Title and I gave you a ROM estimate for the additional cost of changing the camera at \$ 500K. After a first chat with the CCD group at Jet Propulsion Lab, we think this guess was a bit low and are looking into a better estimate. In a similar spirit, we think that a 9 month delay would be ideal for this change; 6 months would be tight but might be possible at somewhat greater cost. The engineering changes are not trivial: in our SPAL proposal, we included several man-months of effort to look at the changes needed for a possible third flight of SOUP with a new camera. If there is a real possibility of making the change for the second flight, we need to divert some engineers' efforts soon to this study. We would appreciate some guidance from you and/or the MSFC Spacelab project whether or not this would be justified now.

Regards,



T. D. Tarbell
SOUP, Experiment 8

cc: R. Lester
E. Urban

 *Lockheed Missiles & Space Company, Inc.*

Research and Development
3251 Hanover Street, Palo Alto, California 94304

March 21, 1986

Mr. Lou Demas
Code EM
NASA Headquarters
Washington, DC 20546

Dear Lou:

As you know, the Solar Optical Universal Polarimeter (SOUP) instrument had some unexpected problems during the Spacelab 2 mission last summer. Despite these setbacks, the instrument provided 24 hours of high resolution observations of the sun, unique and exciting data for solar physicists. Since the mission, we have operated the instrument on the ground in a large number of test configurations. Our goal has been to understand the causes of flight anomalies (by reproducing them in the lab, whenever possible), so they can be prevented for Sunlab. This letter summarizes our findings to date and outlines the changes planned for Sunlab.

Before enumerating SOUP's problems, let me briefly summarize some of its accomplishments to maintain perspective. The telescope is the only diffraction-limited astronomical telescope flown in space, and its performance remains at the theoretical limit after landing. The images were stabilized by active optics to a few milliseconds of arc. Thus, the 6000 frames of white light film are of unsurpassed quality for studying the time dependence fine structure in active and quiet sun. The tunable filter images, although marred by severe blemishes, also show sharp, stable focus in limb observing orbits. Finally, we are very proud of the performance of the operational teams, on-board and on the ground, for their successful activation of this complex experiment in the hectic last day of the mission.

On March 10, I presented a status report on the "SOUP Instrument Anomaly Investigation" to Lockheed management. Copies of the report, on which this letter is based, have been sent to the mission and instrument managers at MSFC. The in-flight anomalies have been grouped into four categories: three significant problems and a fourth set of nuisances which caused negligible losses of scientific data. Roughly half of the nuisances were known before flight and almost all are now understood.

The first serious problem was, of course, the power loss and reappearance. The SOUP telescope suddenly lost all power after 4.5 hours of normal activation and checkout. All power-on commands failed for the next five days until the nominal command suddenly restored the power; it stayed on for 36 hours. The power was lost again when the instrument was being deactivated for landing, and attempts to restore it on-orbit were unsuccessful. Power came on normally at KSC after landing. Despite a variety of tests which have exercised the circuitry beyond its design limits, the problem has never occurred on the ground. The failure analysis report for the power-off

Darlington transistor, which was once suspected of causing the problem, found an extremely low probability that it failed in space. Two other components in the SOUP relay driver circuit which could have caused the problem are undergoing failure analysis now. Although this investigation is not yet complete, no cause within the SOUP instrument has been established to date. In any event, a redesigned and redundant power switching and distribution system will be flown on Sunlab.

The second problem was overheating of the focal plane package, a problem shared by many instruments on Spacelab 2. Although the SOUP thermal design was basically validated in its thermal vacuum test before delivery, overheating was expected based on thermal environmental models received from NASA shortly before launch. However, because of the power problem, our planned approach of powering-down to cool off was not followed, and the overheating had serious consequences as a result. These consequences include failure of the tunable filter camera film advance and partial latent image decay of the white light image. The causes are well understood by post-flight analysis and testing, and a revised thermal design is under way for Sunlab.

Third, severe blemishes on the tunable filter CID camera images have so far rendered them scientifically unusable. These have now been reproduced in our lab by operating the instrument in a vacuum chamber with real sunlight. The most serious causes are bubbles developing in the tunable filter oil and a thin film of contamination depositing on the CID detector. Both of these problems appear only in vacuum, and neither is detectable with the laser light source used in thermal vacuum test before delivery. Solar testing in vacuum, which could have revealed these problems before delivery, was eliminated due to funding limitations. The Sunlab program will include several months of solar testing. We hope it will also include approval to replace the ten-year-old CID camera with a modern CCD. Contamination and noise effects would be alleviated with the CCD camera developed for the Solar Optical Telescope (SOT) project. Some additional work on the tunable filter will also be needed to ensure its performance in vacuum for Sunlab.

We now have confidence in how to refurbish the instrument for Sunlab to avoid the Spacelab 2 problems. The major changes proposed are redundant power on/off circuitry, additional margin in thermal design, replacement of the CID camera with a SOT CCD, and rework of the tunable filter fluid cavity. I will be happy to discuss these matters in more detail or send further information, at your request.

Sincerely,

Ted Tarbell

T. D. Tarbell
Principal Investigator, SOUP Instrument
Dept. 91-30, Bldg. 256
(415) 424-4033

cc: J. D. Bohlin
V. Jones
R. Lester
E. Reeves

Addendum to the Letter on SOUP Problems during Spacelab 2

At the time of the letter, we had operated SOUP on the ground during six months of intensive testing. Suspicions had been raised that a short caused by a metal particle floating in zero g might have caused the problem, and we had not yet received the final evaluations on all suspect parts. However, when all the failure analysis reports were received, none showed any indication that such a failure in space likely occurred.

After NASA agreed that no cause for the power loss had been identified within SOUP, the Spacelab Remote Acquisition Unit (RAU) which provided power and commands to the instrument was put through its normal functional test procedure to see if it was the culprit. It passed the test successfully. Unfortunately, no attempt was made to simulate the precise situation on Spacelab 2. There is, therefore, no satisfactory understanding of the SOUP power loss problem.

The blemishes on the CID images were caused by cryopumping of contaminants onto the cooled detector. The CID was not in a sealed container; rather there was a vent valve which opened at low but not zero pressure. The balloon CCD camera was planned to be in a sealed unit. The bubbles in the tunable filter were caused by a small leak of the index matching fluid, which at very low pressure allowed vaporization of the fluid in the optical cavity. Unfortunately, rotation of the waveplates in zero g brings any bubbles into the center of the cavity. This problem has been solved by understanding and fixing the cause of the leak. The filter also now has an external spring on its expansion bellows to maintain a minimum pressure of 5 psi, which is sufficient to prevent the formation of bubbles. The filter has been tested extensively in a vacuum chamber.

Both the CID enclosure and tunable filter problems were not seen before flight because cost and schedule constraints did not allow a final solar test of the instrument. The power loss could probably have been recovered from with a properly designed redundant power control system. Such a system was not allowed on the Spacelab SOUP program because of the NASA policy at that time to build very low cost instruments for use on the shuttle. Spacelab 2 was "primarily an engineering flight intended to test the Spacelab systems," according to the selection letter for the SOUP investigation. The policy eliminated any redundancy or other design or screening measures for high reliability, on the theory that frequent reflights of modified instruments would be readily available. For the second flight of SOUP on the Sunlab mission, a new power control system designed for high reliability was approved. An appropriate version of that design was planned in the balloon program.



950 N. Cherry Av
P.O. Box 26732 Tucson, Arizona 85726-6732
(602) 327-5511 Telex 0666-484 Aura Noaa Tu

National Solar Observatory

September 19, 1986
0986-085

Dr. James C. Fletcher
Administrator
National Aeronautics
and Space Administration
Headquarters
Washington, D. C. 20546

Dear Dr. Fletcher:

At a recent meeting of solar physicists, the exciting preliminary results from the solar experiments on the Spacelab 2 mission were discussed, and interest in and committment to future developments were very much on everyone's mind. The extraordinary scientific insights gained and the experimental capabilities now available cry out for the orderly exploitation of this hard-won human and technical resource.

The participants were concerned by the possible suspension of the SUNLAB program in light of, for example, the comments reported in AWST (September 1, 1986). While we appreciate the difficult times facing U. S. space science, we respectfully urge you to maintain the momentum of this exemplary program in light of the enclosed resolution.

Sincerely,



John W. Leibacher

Enclosures

cc: Dr. B. Edelson

JWL:lhb



National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of

EM

Dr. Theodore D. Tarbell
Department 91-30, Building 256
Lockheed Solar Observatory
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Tarbell:

The Office of Space Science and Applications (OSSA) has been faced with many difficult decisions in the aftermath of the Challenger accident. We now must plan on 33 fewer equivalent Shuttle flights through 1992 for OSSA than expected prior to the accident. This major reduction in flight opportunities, coupled with significant cost increases resulting from the stretchout of our missions, has forced us to restructure our program. As a result, the Sunlab mission has been put on indefinite hold until such time as the implications of the Shuttle manifest are understood and the possibilities for additional flight opportunities are exhausted. We will continue to support the Solar Optical Universal Polarimeter (SOUP) at a nominal level in FY 1987 while we explore the possibilities for accommodating this investigation. The potential this instrument demonstrated during Spacelab 2, I feel, can best be exploited by concentrating our efforts on the planned High Resolution Solar Observatory (HRSO) instrumentation for which your institution is responsible. HRSO, planned for a new start in FY 1988, is the centerpiece of the Solar Physics Program, and your efforts will be valuable in ensuring its success if we have to terminate the SOUP investigation.

The Sunlab Mission Manager, Mr. Roy Lester, will be in contact with you to make specific contract arrangements associated with this decision.

I would like to thank you for your contributions to and support of OSSA and request your continued patience as we work our way through these difficult times.

Sincerely,

B. I. Edelson
Associate Administrator for
Space Science and Applications



National Aeronautics and
Space Administration

Washington, D.C.
20546

16

Reply to Attn of EM

Dr. Theodore D. Tarbell
Department 91-30, Building 256
Lockheed Solar Observatory
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Tarbell:

In October 1986, the Office of Space Science and Applications (OSSA) informed you that we had to put the Sunlab mission on indefinite hold until the implications of the Challenger accident on the Shuttle manifest were understood. As stated at that time, OSSA was facing a significant reduction in flight opportunities and increased cost associated with the stretchout of our flight programs. Since the situation has not improved, I must regretfully inform you that the Sunlab mission is cancelled and that OSSA no longer plans to refly the Solar Optical Universal Polarimeter (SOUP) investigation. Continued funding of the SOUP investigation is no longer possible.

I assure you we have explored all reasonable possibilities to accommodate your investigation, including the potential improvements in the Shuttle manifest made possible with the increased Orbiter downweight capability, but without success. As you are aware, even after launches of the Shuttle resume, the flight rate will be sufficient to accommodate only a modest number of the many payloads that exist or else are ready for launch. The fact is that OSSA lost a substantial number of Shuttle flights, and OSSA priorities would not allow for a reflight of your investigation until 1995 at the earliest. These considerations have led me to this unpleasant decision.

Again, I regret that this action is necessary, and I thank you for your patience. The Marshall Space Flight Center will be contacting you about the specific steps to be taken. If you have any questions, please contact Mr. Louis Demas at (202) 453-1690 of the Shuttle Payload Engineering Division.

Sincerely,

L. A. Fisk
Associate Administrator for
Space Science and Applications



National Aeronautics and
Space Administration

Washington, D.C.
20546

ES (JDB)

Reply to Attn of

Dr. Theodore D. Tarbell
Lockheed Palo Alto Research Laboratory
Dept. 91-30/Bldg. 256
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Tarbell:

Your proposal, entitled "Investigation of Solar Active Regions at High Resolution by Balloon Flights of the Solar Optical Universal Polarimeter (SOUP)," was submitted in response to NASA Research Announcement 88-OSSA-04. A panel of your peers has carefully and fully reviewed the 12 proposals submitted, and they have also been scrutinized internally by NASA for their technological, managerial, and financial implications. Your proposal was recognized to have superior merit in this competition. Therefore, it is with pleasure to tell you that your investigation is selected for the Definition Phase of this program. You are hereby appointed as the Principal Investigator of the investigation named above, and all of the team members listed therein are recognized as your Co-Investigators.

For your information, enclosed is a listing of the three proposals that have been selected, all under the following identical conditions:

(i) The Max '91 Solar Balloon Program (SBP) is formally planned for a four year period, beginning January 1, 1989. Any program activity beyond that period will be approved on a case by case basis. Nominally each selected investigation will be provided in this period with one test flight and one long-duration flight, resources permitting.

(ii) Each selected Max '91 SBP investigation will receive \$200K funding for a Definition Phase to last about four months, beginning January 1, 1989. The purpose of this Definition Phase is to evaluate the investigations uniformly in detail for cost, technical feasibility, schedule, and compatibility with the funding profile under which this program must be carried out. In this latter regard, you should be aware that the financial resources available for this program in Fiscal Year (FY) 1989 are only of the order of one half that required, insofar as they can be estimated at the present time. Therefore, careful planning on your part to minimize funding requirements in the first two years will especially help to insure that your investigation will be confirmed for flight.

(iii) During the Definition Phase, each investigation is expected to develop a clear description of its management approach, including organizational charts, and summary statements of the authority and responsibility of each staff position. In particular, NASA is concerned that a professionally experienced management team be identified with each

investigation. Likewise, your method of program control (e.g., schedule forecasting and risk analysis) must be developed. The design of the hardware planned for your investigation must be refined in sufficient detail to assure NASA that no major obstacles prevent its timely construction and testing. Finally, a realistic project plan must be developed showing that your investigation can be carried out in the epoch of the current maximum of solar activity, at a total cost not to exceed that proposed in your proposal through 1992.

(iv) At the end of the Definition Phase, all Max '91 investigations will be subject to a Confirmation Review conducted by the Space Physics Division. Those investigations passing this review will be confirmed for a test flight of their equipment, nominally to be conducted within the continental United States, as soon as the payload and the necessary balloon support equipment can be readied. At the present time, it is expected that not more than \$400K for the remainder of FY89 will be available for each investigation approved at its Confirmation Review.

(v) Each investigation confirmed for a test flight will be required to support several project reviews a year, at which it must continue to demonstrate that it can achieve a meaningful flight schedule consistent with its allocated resources. In general, the Max '91 SBP is a level-of-effort program. Therefore, a cost overrun by any one investigation is expected to be offset by appropriate descoping of the investigation by the Principal Investigator. Failure to do so will be grounds for termination of that investigation.

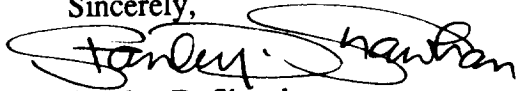
(vi) If the test flight is successful, at least one long duration flight (at a site to be later designated) will be scheduled, pending the state of the solar activity cycle and the availability of launch sites, flight systems equipment, and financial resources.

(vii) The three selected Max '91 SBP PI's will be expected to join together in a Max '91 Science Working Group (SWG), to be chaired by a NASA Project Scientist to be appointed in the future. The function of the SWG will be to coordinate the activities of the SBP payloads both internally as a group as well as externally with regard to the rest of solar maximum programs as may be funded by NASA, other U.S. agencies, and foreign nations.

You may call the Max '91 SBP Program Scientist, Dr. David Bohlin (202/453-1514) to discuss the conditions of this selection if you desire. If acceptable, you should submit written notice of the acceptance of this selection under the conditions noted in this letter to Dr. Bohlin within five working days of the receipt of this letter. Thereafter you will be contacted with instructions for ensuing activities.

On behalf of NASA, I would like to offer our congratulations to you and your science team for submitting a successful proposal. The Max '91 SBP is expected to be a main part of our flight opportunities in solar physics during the coming solar maximum. We look forward to working with you for the successful completion of your investigation.

Sincerely,

A handwritten signature in black ink, appearing to read "Stanley D. Shawhan". The signature is written in a cursive style with a large, sweeping initial "S".

Stanley D. Shawhan
Director
Space Physics Division

Enclosure

a/s



Research and Development
3251 Hanover Street, Palo Alto, California 94304-1191

17 November, 1988

Dr. Stanley D. Shawhan
Space Physics Division
Code ES (JDB)
National Aeronautics and Space Administration
Washington, DC 20546

Stan
Dear Dr. Shawhan:

Thank you for your letter dated November 9 (received Nov. 16) selecting my investigation of solar active regions by balloon flights of SOUP. I am pleased to accept the offer and begin the Definition Phase of the program. The conditions of selection are acceptable; however, I have several concerns and recommendations which I will now discuss. We share a common goal of getting the greatest possible scientific return with the limited budget available, and the approach in my proposal was consistent with this. I hope you will direct that the following issues of cost containment and scientific productivity be addressed before and during the Definition Phase.

As you know, I proposed to use the NASA-provided gondola and gimbal pointing system, "which NASA expects to develop, as part of this Max '91 LDBF Program," according to the Research Announcement. The selection letter does not mention this equipment. My proposal included some effort to assist in specifying the performance and interfaces, but not to acquire the hardware. During the time period of my Definition Phase, NASA must gather the performance requirements and develop a management plan to obtain and test this hardware in a timely fashion.

I proposed a program of three flights, extending through October, 1993. This has been reduced to nominally two flights and truncated to end in 1992. The loss in scientific knowledge from deleting a third flight is substantial, although impossible to predict in detail at this time. However, the entire effort proposed for 1993 is scientific data analysis; without it, only 3-6 months exist for data analysis following the second flight. This is not enough time to complete the initial processing and distribution of the data to co-investigators, not to mention serious scientific study. Support for co-investigators was already severely limited in the proposal to keep costs down. The scientific investigation must not be cut further. I urge that a data analysis phase of at least 12 months

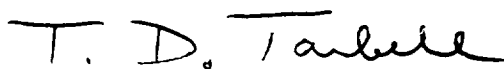
duration after receipt of the scientific data be guaranteed, just as it is for NASA spaceflight scientific investigations, including short shuttle flights.

I have a few comments about the management approach outlined in your letter. I agree completely that the investigation needs an experienced, professional management team, and my proposal included a full-time project manager/chief engineer. A realistic program plan will be developed in the definition phase. However, NASA project management needs to agree that this is a lean, build-to-cost program with far less formal oversight than a spaceflight program. Otherwise, the budgets discussed for this program will simply not get the job done. My proposal did not include support for several project reviews a year, if they have the scope of a traditional PDR or CDR. Likewise, we did not include a formal quality assurance plan or oversight by a separate quality control organization. We must reach agreement early in the Definition Phase to an informal but professional management approach, or it will be impossible to complete the investigation without large cost increases over what was proposed.

The Definition Phase is stated to last about four months, beginning January 1, 1989. Our recent experience with NASA contracts has shown tremendous variation in the time required to start work on a new program, ranging from a few weeks to as long as seven months. There is an open contract with MSFC for SOUP data analysis which might be used for the balloon investigation. I urge you to authorize pre-contractual funding as soon as possible and then to push hard on the contracting process for prompt negotiation and sign-off of the contract, so that real work on the project can begin soon.

The SOUP team and I are delighted to be part of the Max '91 Solar Balloon Program. Many of us have been working for more than a decade on flying this type of instrument above the atmosphere, and we are grateful for this timely opportunity.

Sincerely,



Theodore D. Tarbell
Senior Staff Scientist
Solar and Astrophysics Laboratory



National Aeronautics and
Space Administration

Washington, D.C.
20546

MAY 23 1989

ES

Reply to Attn of:

Dr. Theodore D. Tarbell
Lockheed Palo Alto Research Laboratory
Dept, 91-30/Bldg. 256
3251 Hanover St.
Palo Alto, CA 94304

Dear Dr. Tarbell:

With the Definition Phase for the Solar Optical Universal Polarimeter (SOUP), being initiated and confirmation for development scheduled in the late summer, it is appropriate to discuss the criteria upon which this confirmation decision will be made. Confirmation will be based on the total cost of the investigation, an effective cost control plan, the ability to develop the hardware in a timely manner and the likelihood of achieving the scientific objectives at this time.

As you recall in the letter selecting SOUP for Definition for the Max' 91 SPB, it was stated that the funds available for the total SBP in FY 1989 were about one half of that required and that careful attention must be taken to minimize funding in the first two years and keep total costs at the proposed level. The FY 1989 situation has not changed and we now face a constrained budget in FY 1990 and beyond. In view of this fiscal situation the first flight of SOUP is delayed until December 1993. Therefore, for planning purposes the funds available for the instrument development and associated data analysis are as follows:

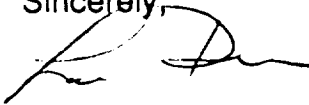
FY89	FY90	FY91	FY92	FY93	FY94	TOTAL
\$0.2M	\$0.1M	\$0.5M	\$1.7M	\$1.5M	\$0.5	\$4.5M

Your plan for the development of the SOUP should assume that these are the maximum funds available and consideration should be given to descoping options to stay within these resources. If the situation should improve we will attempt to accelerate your schedule.

At the conclusion of the Definition Study there will be a review of the study results upon which confirmation for development and flight will be based. At this review you should be prepared to discuss the SOUP development plan, development schedule and probable launch dates in light of the above funding profile, cost control options (descopings) and launch site preferences. Also, you should discuss the latest predictions for the Solar Cycle 22 and the estimates of solar activity and the corresponding expected scientific results for the two flights of SOUP.

I once again would like to emphasize that the above funding profile is for planning purposes only and does not represent a commitment on the part of NASA at this time. We will complete planning and commitments to the Max '91 SPB after the Definition Phase reviews.

Sincerely,



Louis J. Demas
Max '91 SPB Program Manager

cc:

ES/Shawhan
/Bohlin
/Kane
/Jones

ORIGINAL PAGE IS
OF POOR QUALITY



National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of ES(JDB)

JAN 2 1990

Dr. Theodore D. Tarbell
Dept. 91-30
Lockheed Palo Alto Research Laboratory
Palo Alto, CA 94304

Dear Dr. Tarbell:

I deeply regret to confirm the decision related to you by telephone on December 11, 1989, that your Max '91 Solar Balloon Program (SBP) investigation, entitled Solar Optical Universal Polarimeter (SOUP), must be canceled. This decision in no way reflects on your performance as the Principal Investigator of your investigation or that of your science team. Rather it is compelled by limitations of the current and future fiscal year budgets available to the Space Physics Division that are beyond our control and that were quite unexpected as recently as a month ago. We assure you that we have explored every reasonable alternative to this most unfortunate action, but after extensive deliberations with Dr. L. A. Fisk, Associate Administrator, Space Science and Applications, it is apparent that no other decision can be made.

It is our desire that this effort be closed out in an orderly manner that preserves the progress in design studies that may have been accomplished, allows your key project personnel to transition smoothly to other activities, and develops at least a report, if not hardware relevant to the future interests of NASA's Solar Physics program. To this end, we would appreciate a plan for the close-out of your Max '91 SBP effort by the end of January 1990. This plan may assume that whatever funds have been made available to date will remain at your disposal, although we do not guarantee such approval at this time. At a minimum, your plan should assume no further SBP funding and delivery of a final report by the end of Fiscal Year 90, although you may propose alternative options for consideration as part of the Solar Physics Research & Analysis Program. None of your current funds should be further obligated until your plan is approved. The details are left for you to develop in conjunction with your science team and institution management. David Bohlin and Louis Demas, the Program Scientist and Manager, respectively, will be happy to consult with you as you desire.

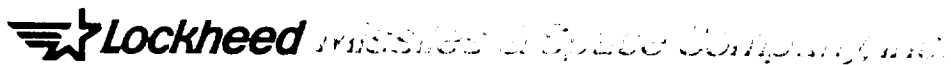
Again, I express our regret that budget limitations left no recourse to this unfortunate decision. Please convey this news to your science team and management personnel. Questions may be directed to Dave Bohlin.

Sincerely,

A handwritten signature in black ink that reads "S. Shawhan". The signature is written in a cursive style with a large, prominent "S" at the beginning.

Stanley D. Shawhan
Director
Space Physics Division

cc:
ES/ Bohlin
ES/Demas
E/Alexander
GSFC-WFF/Wm. Johnson
MSFC/ES01/Tandberg-Hanssen



Research and Development
3251 Hanover Street, Palo Alto, California 94304-1191

February 9, 1990

Dr. Stanley D. Shawhan
Space Physics Division (ES)
NASA Headquarters
Washington, DC 20546

Dear Dr. ^{Stan} Shawhan,

I have the unhappy task of responding to your letter of January 2 (received January 10) which cancelled the present SOUP-on-a-Balloon investigation. I can understand the budgetary problems which motivated you to take this drastic action, and I appreciate your efforts over the past two years to make the program happen despite the many obstacles. Still, I'm very disappointed that NASA could not support a small, well-considered project like this, which would produce exciting scientific returns in just a few years. I believe that the priorities of the Office of Space Science and Applications should be altered to increase support of such projects. They can produce real advances in a field during the decade-long waits for major or moderate missions, while recruiting and training young scientists. The widespread support among the scientific community for such a change of priorities was repeatedly stressed at the Space Physics Strategy Workshop, which we both attended in Baltimore a few weeks ago. I will continue to add my voice to those of the various advisory committees which continually urge this reform of NASA policy. Perhaps you can suggest more effective tactics for me and my colleagues to help you make progress in this area.

The SOUP investigation proposed to study the magnetic structure and evolution of active regions at very high resolution. The importance of obtaining these observations has not diminished over the years. Rather, the tantalizing glimpses of such observations from Sacramento Peak, Big Bear, and the Canary Island observatories have convinced a very broad segment of the scientific community of their fundamental importance for progress in understanding solar activity. The engineering evaluation which has been carried out to date has revealed no serious technical obstacles to our plans for balloon flights of SOUP. The proposed investigation was, and is, a feasible way to get important and unique scientific observations.

Your letter directs me to submit a plan for closing out the effort by the end of FY 90 and spending the remaining funds (about \$120K) in a constructive way that preserves the progress to date. In keeping with this direction, I have constructed the following plan for continuing the research which is the basis of the SOUP investigation. Progress will be made on two fronts, ground-based observations and programmatic and engineering efforts to create a future balloon flight opportunity. We must abandon the previous plans for FY 90, which were to build an improved copy of a CIP CCD camera dedicated to ground- and balloon-based observing and to support a Ph.D. student from Utrecht for the balloon project. Instead, the major elements of our plan are:

- 1) Exploring alternate plans for a balloon flight. Dr. John Davis at MSFC has proposed to build an engineering model solar pointing system using the SOUP requirements to guide the design. We propose to support him in these efforts, at a minimum with information and consultation. We are also searching for a funding partner in another agency or foreign country and an existing pointing system (or components) which could accommodate SOUP. For example, we have had very preliminary discussions with solar physicists at the Air Force Geophysics Lab regarding the use of AF ballooning equipment, facilities, and funding. Our goal is to derive a plan for a flight program, perhaps with descoped scientific objectives, which could take place during the Max '91 period at a much-reduced cost to NASA. The appropriate proposals, prepared using Lockheed internal funds, would be submitted when necessary.
- 2) Observing with SOUP instrument components at the Swedish Solar Observatory on La Palma. As you know, we have carried out very successful observing expeditions in 1988 and 1989 to obtain exciting high-resolution solar data and to test components of the OSL Coordinated Instrument Package. Both runs have overlapped with Max '91 observing campaigns and have produced unique data-sets, which we have analyzed and published and continue to study. In addition, Dr. Bohlin has stated that these images and movies have been very effective in rallying support for the OSL mission. Our group will observe again this year, supported jointly by the National Science Foundation, the Swedish Royal Academy of Sciences, the Lockheed Independent Research program, and the OSL project. I propose to use a substantial fraction of the remaining SOUP funds for scientific analysis and publication of the data. This will include partial funding for two graduate students (from Stanford and Utrecht) who are presently analyzing these data, and it may also support other collaborations with SOUP science team members.
- 3) Completing tests in progress of low-voltage piezoelectric transducers at stratospheric pressures. These components are the actuators for the image motion compensation (IMC) system which

enables SOUP to obtain diffraction-limited images on a partially stabilized platform. The Spacelab 2 version of the instrument used high-voltage devices which cannot be used on a balloon flight. Completing these tests should prove the feasibility of our modified IMC design.

4) Submitting a final report. This will summarize the engineering and programmatic work completed as well as the scientific results from ground-based observing.

I hope this plan is acceptable. I feel it represents the wisest use of the remaining funds for advancing high-resolution solar science, which is the main goal of the SOUP team at Lockheed. We remain committed to working with you to fly instruments to obtain this knowledge, whether they be on the shuttle, balloons, or satellites.

Best Regards,

Ted Tarbell

Dr. T. D. Tarbell
Principal Investigator, SOUP

cc: J. D. Bohlin
L. Demas
J. Davis (MSFC)
S. Kane



Report Documentation Page

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16. Abstract The Solar Optical Universal Polarimeter flew on the shuttle mission Spacelab 2 (STS-51F) in August, 1985, and collected historic solar observations. SOUP is the only solar telescope on either a spacecraft or balloon which has delivered long sequences of diffraction-limited images. These movies led to several discoveries about the solar atmosphere which were published in the scientific journals. After Spacelab 2, reflights were planned on the shuttle Sunlab mission, which was cancelled after the Challenger disaster, and on balloon flights, which were also cancelled for funding reasons. In the meantime, the instrument was used in a productive program of ground-based observing, which collected excellent scientific data and served as instrument tests. This report gives an overview of the history of the SOUP program, the scientific discoveries, and the instrument design and performance.			
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