1/2 GRANT
IN-52-CR
326546
P 14

# FINAL REPORT

# ANALYSIS OF OCULAR TORSION DATA FROM SPACELABS D-1 AND SL-1

## NASA Grant NAGW-1377

## December, 1990

Principal Investigators:
C.M. Oman and L.R. Young
Man Vehicle Laboratory
Center for Space Research
Massachusetts Institute of Technology

Author: C.M. Oman

(NASA-CR-187799) ANALYSIS OF OCULAR TORSION DATA FROM SPACE LABS D-1 AND SL-1 Final Report (MIT) 14 p CSCL 06P

N91-15682

Unclas
G3/52 0326546

## 1. Technical and Administrative Background:

A bi-national team of investigators under the direction of Professor L.R. Young of MIT conducted a series of preflight, inflight, and postflight vestibular experiments on Spacelab missions Sl-1 (October, 1983; Contract NAS9-15343) and D-1 (November, 1985; Contract NASW-3651). Two portions of the investigation, the "sled" and "dome" functional objectives (FOs), involved recording the torsional motion of human subject's eyes. "Sled" testing was conducted preflight and postflight only on SL-1, and on the D-1 mission, inflight testing was also accomplished. Pre-postflight ground based sled testing was accomplished on both missions using the NASA Laboratory Sled in Baseline Data Collection laboratories at KSC and DFRC. On the D-1 mission, the ESA Space Sled was used for on orbit experiments on 2 subjects. Pre and postflight D-1 testing also utilized the ESA Space Sled protoflight hardware.

In the SL-1 sled and dome experiments, preflight and postflight ocular torsion (OT) was recorded on 35 mm film using a Nikon motor driven camera (2.6 frames/sec). Film was to be analyzed by measuring the motion of contact lens landmarks using a Hermes senior film scanner made available to us on a per hour charge basis by the MIT Laboratory for Nuclear Science(LNS). (LNS maintained a scanning facility in order to digitize particle interaction data from bubble chamber photographs.) This manual 35 mm film analysis method had been developed by Byron Lichtenberg for his PhD Thesis in the late 1970s, and had been used in several other subsequent thesis research efforts. However, an inflight failure of the dome experiment camera flash unit led the crew to utilize the Spacelab video camera as an alternative contingency method for imaging the eye in this FO.

Immediately after the SL-1 mission, our laboratory began to develop a suitable method for analysis of the video data. The higher frame rate of video had the advantage of reducing temporal aliasing of torsional nystagmic eye movements, as compared with the 35 mm camera method. However, because of the different format, high frame rate (30 Hz.) and large number of images collected, manual analysis was considered impractical. Under Dr. Young's supervision, J.A. Parker investigated the feasibility of computerized OT analysis of video images. (This feasibility study was funded primarily through grants from the James Picker Foundation and NIH, with partial support from NASA Ames Grant NAG2-88). Parker developed a 2 dimensional cross correlation technique for tracking the motion of two "regions of interest" on the iris, and successfully tested it using digitized photographs of the eye. Although the method was not actually evaluated on experimental data, Parker's results were judged sufficiently encouraging in 1984 that the decision was made to use video OT recording in certain experiments on the upcoming D-1 mission: the preflight, inflight, and postflight "dome" experiments, and preflight NASA Laboratory Sled tests. However, a technically conservative approach was taken for the MIT-Canadian preflight, inflight, and postflight experiments using the ESA Space Sled. These experiments were conducted with 35 mm photography, as originally planned.

The data analysis and publication phase for each mission was originally funded for six months. The D-1 data analysis activity was assumed to be concurrent with a SLS-1 effort (subsequently postponed), and only $8K were originally allocated for D-1 data analysis and $3K for publications. Because of the change in OT data analysis methodology; to resolve problems with analysis of (ARU/CDTR) digital recorder data obtained in a head movement monitoring portion of the investigation; and to cover unanticipated travel costs associated with the D-1 DFRC landing, MIT requested additional $175K funding in 1986. Funding allowed us to acquire computer hardware for analysis of head movement and video analysis of ocular torsion data, and complete and publish an analysis of SL-1 and D-1 the ARU/CDTR head movement data.

Shortly thereafter, however, we encountered a new obstacle for 35 mm film OT data analysis: MIT/LNS decided to close down the 35 mm film scanning facility. LNS offered us one of the Hermes scanners and associated computer equipment on indefinite loan. However, the cumbersome device had to be moved, and significant repair and calibration of its 25 year old electronics and optics were required. After discussions with Dr. R.J. White and D. Harris of NASA, in July of 1987, Dr. Oman submitted a proposal requesting funding of $54K for the period 10/1/87 through 2/28/89 to resolve SL-1 and D-1 OT analysis problems. Grant NAGW-1377 ($55K funding) was received 11 months later for the period 6/1/88 through 5/30/89. A no-cost extension was eventually granted through 12/31/89.

## 2. Objectives:

MIT/MVL Grant NAGW-1377 funding was allocated to:

1) support reinstallation and repair of the Hermes Senior 35mm film scanning machine in the basement of our MIT building, recalibration, and testing.

2) provide 14 months graduate student support for development and testing of a microcomputer based OT video image processing system. (Computer hardware had been obtained using previous funding.) (The original MIT proposal requested 9 months graduate student support, but this was changed to 14 months in final budget negotiations to account for the 11 month delay in receipt of grant funds.)

3) provide funding to defray additional publication costs for several D-1 FOs (see publication list, Sect. 4 below).

The MVL graduate student research assistant, Mr. Andrew Alston, was able to complete the video OT analysis system development in 13 months. The remaining funds were used to provide partial support (453 hrs) for an undergraduate student assistant, Mr. Mawuli Tse, who scanned 35 mm film from the SL-1 and D-1 missions. Tse subsequently analyzed D-1 35 mm sled data as a related but unfunded SB Thesis project.

We were aware from the outset of this project that costs of the actual scanning operation were difficult to estimate, and that a best effort approach with available funds was appropriate, since there were several large data sets to be analyzed. It was agreed that in data analysis, the priority would be: D-1 35 mm sled data; SL-1 35 mm sled data; D-1 sled video, SL-1 dome video, D-1 dome video.

During the initial period of this grant, Dr. Young was on sabbatical leave, so Dr. Oman served as Principal Investigator, and supervised the Hermes scanner repairs and Alston's video OT analysis thesis work. Upon his return, Young supervised Tse's thesis and is responsible for the remaining OT scanning and analysis effort.

The following section summarizes results and publications which have issued from NAGW-1377 funding:

## 3. Technical Results:

3.1 Hermes 35 MM Film Scanner Repairs: As planned, the scanner was moved from LNS storage to the MVL, and was restored to functioning condition by technicians R. Renshaw and H. Landers. Alston, Tse, and Oman reinterfaced the Apple IIe computer (which controls such functions as film advance/rewind and projector selection, recording of the operator's cursor coordinates, and calculation of torsion angle and statistical estimation of measurement repeatability) and data format conversion methods .

3.2 Manual 35 MM Film Scanning: Alston trained Tse in scanner operation. Tse's scanning concentrated on the D-1 flight and ground data obtained from the ESA sled on the two subjects who participated in both preflight, inflight, and postflight testing. SL-1 data analysis targeted subjects C and D who participated in both the US and European vestibular experiments.

Scanning of these data sets proved more difficult than with comparable photos taken of subjects in our own laboratory during earlier thesis research efforts. This was largely due to problems encountered with focus, poor contrast of iral landmarks (particularly in dark eyed subjects), and significant percentage loss of data samples due to blinks and lid droop (probably related to crew fatigue, which was considerable). Film judged "unscannable" due to poor contrast was returned to JSC for "push" re-processing, and some was successfully rescanned. Current status of scanning completion is:

| Subject Code | Total film rolls | Scanned | Unscannable |
|---|---|---|---|
| SL-1 mission: | | | |
| A | 18 | 0 | |
| B | 17 | 0 | |
| C | 15 | 12 | 1 |
| D | 11 | 9 | 1 |
| D-1 mission: | | | |
| E | 15 | 7 | 4 |
| H | 17 | 10 | 1 |

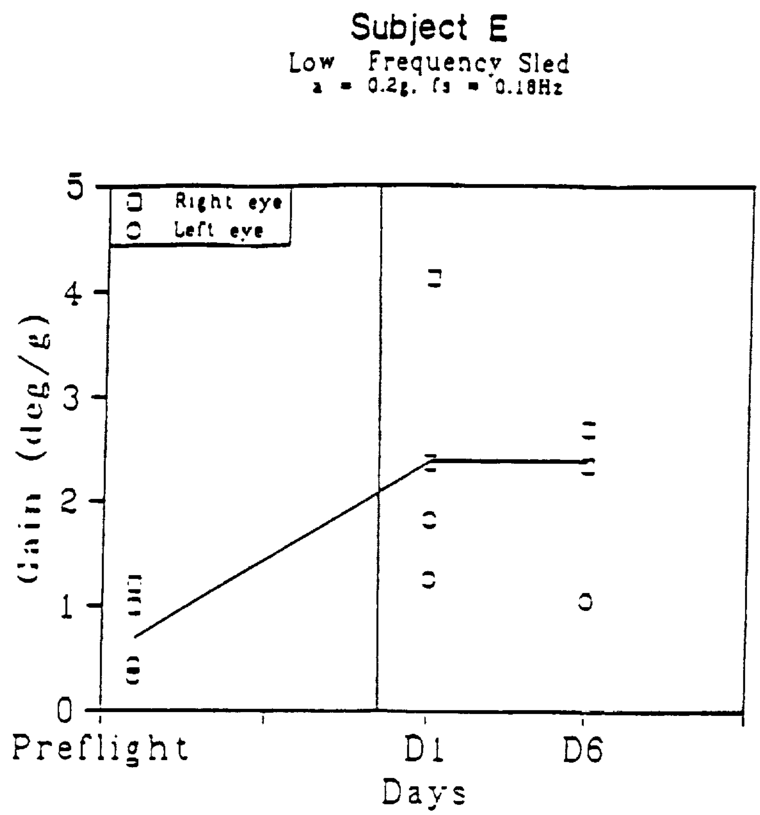


Figure 1: Variation of gain over time prior to launch and during weightlessness for subject E at low frequency.

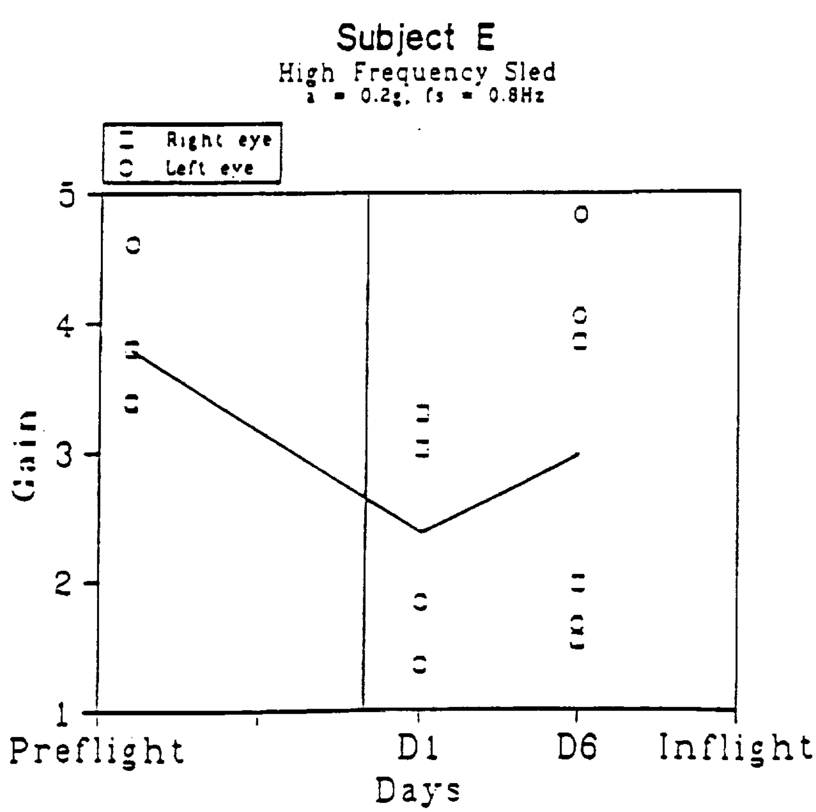


Figure 2: Variation of gain over time prior to launch and during weightlessness for subject E at high frequency.

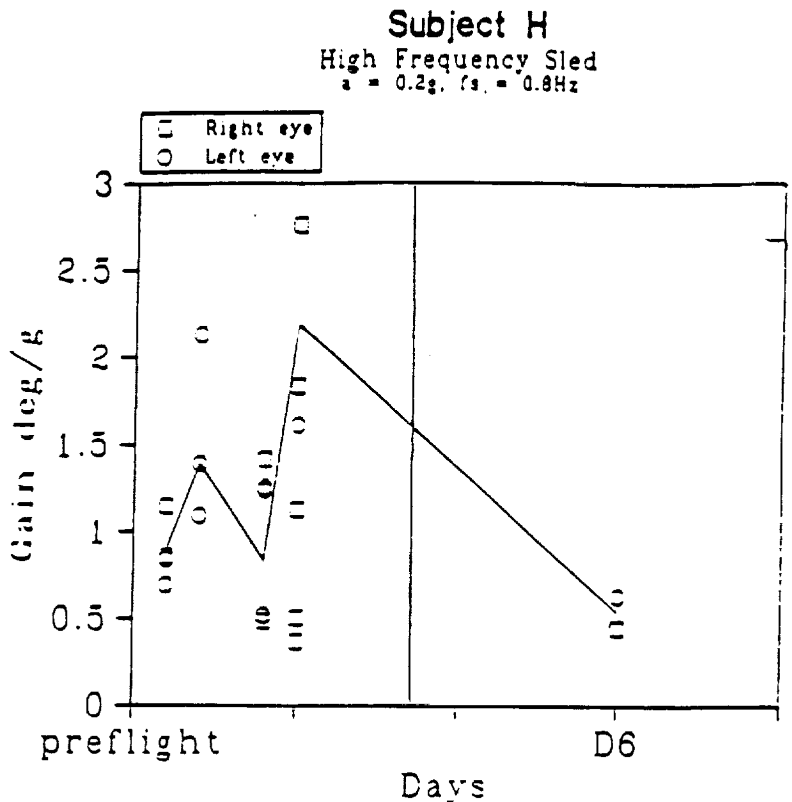


Figure 3: Variation of gain over time prior to launch and during weightlessness for subject H at high frequency.

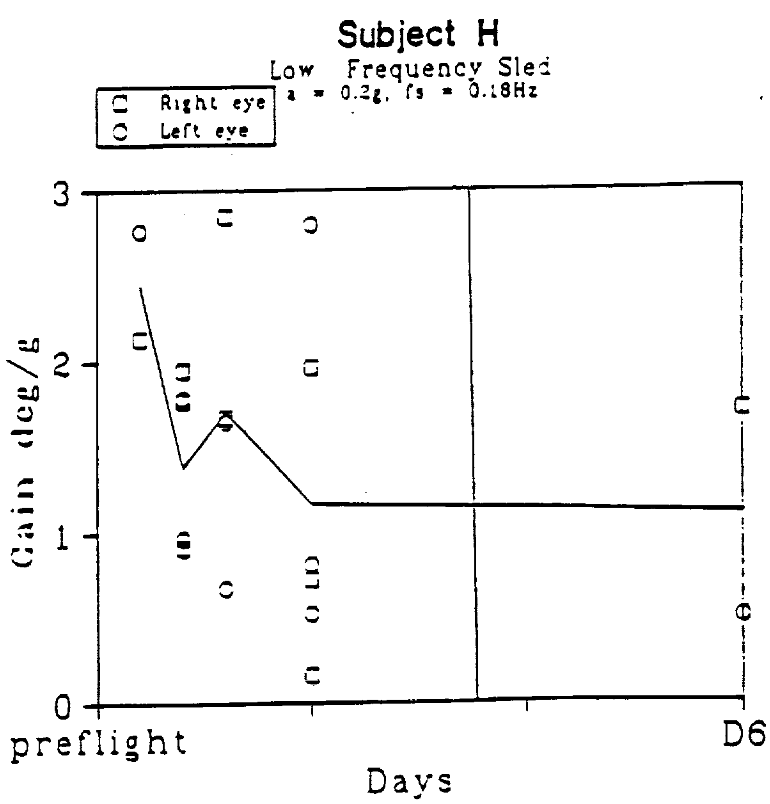


Figure 4: Variation of gain over time prior to launch and during weightlessness for subject H at low frequency.

3.3 Analysis of D-1 Sled 35 mm OT Data:

Tse analyzed the scanned 35 mm OT data set from the two D-1 subjects who participated in both preflight and inflight ESA sled experiments. (Analysis of postflight data from these subjects has not yet been attempted due to delays resulting from the need to push-reprocess some of the film.) Tse recoded portions of Arrott's (1985) sled sinusoidal OT analysis software for the IBM PC, writing in C and MATlab. This analysis consisted of offset removal and high pass filtering of the OT time series, calculation of the cross correlation function of the data beginning after the third stimulus cycle, phase folding, and sinusoidal curve fitting. Due to the large number of missing samples in some records, Tse adopted an ad-hoc replacement procedure, substituting each missing point with the nearest "good" data that was an integral number of stimulus cycles away. Methods and results of his analysis are described in his SB Thesis (Tse, 1990). For both subjects, at the low frequency (0.18 Hz), response gain (deg/g) was generally smaller and variability larger than at high frequency (0.8 Hz). This trend for a smaller gain at high frequency was also observed earlier in ground tests by Lichtenberg (1979). As shown in Figures 1-4, gain in the two subjects (E and H) was typically greater preflight than in weightlessness (mission days 1 and 6). Tse's analysis of the D-1 35 mm preflight and inflight data is regarded as preliminary.

3.4 Microcomputer system for analysis of video ocular torsion:

Alston and Oman developed and tested the video OT analysis computer workstation shown schematically in Figure 5, and described in detail in Alston's thesis (Alston, 1989). The goal of this work was to implement, test and further develop Parker's (1985) digital OT analysis algorithm using actual experiment data. The system constructed, shown in Figure 5, was designated "TOMAS" by Alston. Images are grabbed via a computer controlled Super Beta VCR videotape recorder. C code developed by Alston determines translation of 2 image landmarks by rectangular, 2 dimensional crosscorrelation tracking of two regions of interest in the image, and determines OT by calculation of the inverse tangent of the slope of a line connecting the two landmarks. Alston added compensation of each test image based on reference image mean intensity to the algorithm proposed by Parker. Correction for head movement relative to the camera was made by measuring the rotation of a line connecting two biteboard fiducial marks located at the bottom of each frame. A non linear prefiltering technique was developed to enhance the contrast of landmarks.

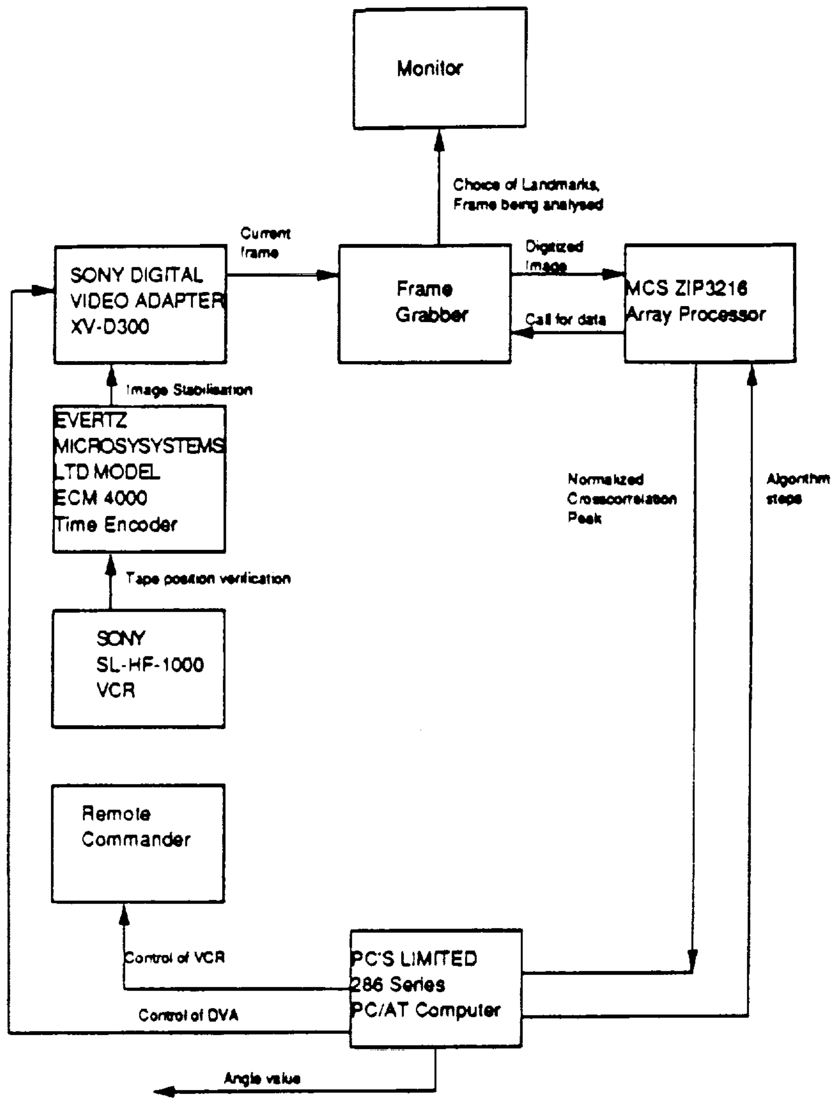


Figure 5: TOMAS OT Analysis Workstation

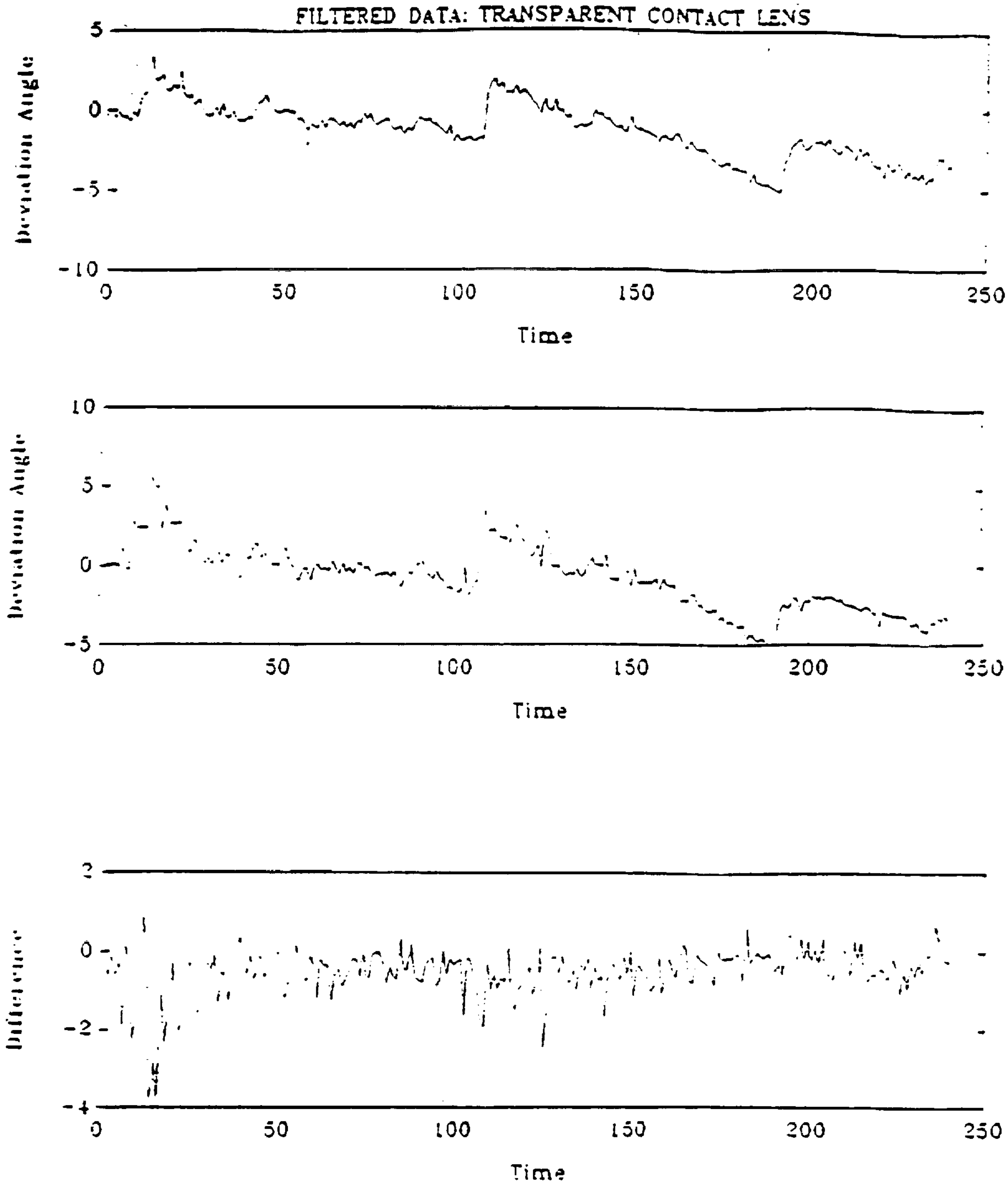


Figure 6: Tracking eye rotation with a transparent lens with black marks. After filtering. Top and middle : two different measurements of the same videotape input; bottom : difference between the two measurements. The sample standard deviation of the difference is .64 degrees, suggesting a measurement standard deviation of .45 degrees.

Applied to "synthetic" data consisting of dark marks on a bright background, an average torsion measurement bias of less than 0.05 degrees and a precision of 0.1 degrees (SD) were obtained using the system. Real data was evaluated from the MIT Canadian Spacelab D-1 "dome" and "sled" experiments. It quickly became apparent that natural iral landmarks in this data set were not generally usable for OT analysis with this system, due to inconsistent focus, relatively weak landmark contrast, loss of contrast (possibly associated with the 2 or 3 stage (e.g. NASA Select - UMATIC - SuperBeta) video data conversion process, inadequate sled helmet lighting, and frame grabber "salt-and-pepper" noise. Moving corneal reflections from rotating dome spots were also troublesome. However, with care, the high contrast landmarks on the soft contact lenses worn by the dome subjects could be tracked. An example is shown in Figure 6. It was noted that "lid droop", which had been noted in many of our 35 mm sled film frames, was also characteristic of much of the dome data. We believe that our approach of rectangular correlation tracking of two landmarks on opposite sides of the pupil has significant advantages over an alternative approach of one dimensional circumferential sampling of the iris image about the center of the pupil, because in real data, the upper hemisphere of the iris is often blocked from view.

System performance limits were investigated. For the D-1 dome data samples were rescanned, and a consistency of 0.45 degrees was obtained when iral/lens mark contrast was good. A direct comparison of the computerized method with manual analysis of the same images using our Hermes scanner supported the hypothesis that the two methods are potentially comparable in accuracy. Alston also analyzed a small amount of video data obtained from the Spacelab IML-1 MVI experiment, in which subjects wore opaque black corneal contact lenses with two white dot landmarks. Precision was significantly improved, and estimated to be 0.1 deg. For an image with two landmarks, TOMAS requires 13 seconds per frame. To track two landmarks and two biteboard fiducials, 25 seconds per frame are required. However, once the system operator has chosen a reference frame, analysis of hundreds of subsequent frames can proceed automatically. These times compare with an average of 6 minutes per frame for D-1 35 mm data analysis.

At present, the TOMAS OT analysis system speed is limited by computer system architecture, and lacks graphical results display and editing features. Much time is wasted moving images from the frame grabber to the image processing board via the microcomputer bus. Using hardware available today, the bus bottleneck problem could be avoided in a second generation system built using the same basic algorithmic approach.

In his thesis, Alston suggested that soft contact lens landmark tracking could also be improved by using circularly symmetric, broader spatial frequency lens landmarks, and by using a larger diameter lens, locating the landmarks over the white sclera, rather than over the iris. Young has subsequently adopted some of these suggestions in the design of a new series of contact lenses for his upcoming SLS-1 experiment, which relies exclusively on video analysis.

Although the TOMAS system was intended only to track contact lens landmarks, its inability to track natural iral landmarks represents a basic limitation. We believe natural landmark contrast can be improved if more care is taken to adjust and maintain image grey scale through the multi-step video recording and tape duplication problem. Vertical resolution could be improved by use of a playback recorder with a dynamic tracking head. Salt and pepper noise can be reduced by median filtering and resampling/averaging the same frame. However, if the goal is to track natural landmarks, three other significant obstacles remain:

a) Iris features temporally vary in character as pupil diameter spontaneously changes due to naturally occurring hippus.

b) Iral landmark contrast is poor under infrared illumination used in many experimental applications to achieve subjective darkness.

b) Iral landmarks are three dimensional structures, so contrast varies somewhat with eye movement and the resulting illumination angle.

A paper describing the TOMAS system is presently in preparation by Alston and Oman.

**4. Publications:** (supported in part by this grant)


Alston, A.E. (1989) "An integrated system for tracking of landmarks on video data: TOMAS, the Torsional Ocular Movement Analysis System", SM Thesis in Operations Research, Massachusetts Institute of Technology, Cambridge, MA, June 1989

Arrott, A. P., L. R. Young and D. M. Merfeld. (1990). "Perception of linear acceleration in weightlessness." Aviat. Space Environ. Med. **61**: 319-26.

Oman, C. M. and M. J. Kulbaski. (1988). "Spaceflight affects the 1-*g* postrotatory vestibulo-ocular reflex." Adv. Oto-Rhino-Laryng. **42**: 5-8.

Oman, C. M. and I. Shubentsov. (1990). <u>(Abstract): Space motion sickness intensity correlates with average head angular acceleration</u>. 1990 Annual Scientific Meeting of the Aerospace Medical Association.

Oman, C. M., L. R. Young, D. G. D. Watt, K. E. Money, B. K. Lichtenberg, R. V. Kenyon and A. P. Arrott. (1988). MIT/Canadian Spacelab experiments on vestibular adaptation and space motion sickness. <u>Basic and applied aspect of vestibular function</u>. Hong Kong, Hong Kong University Press.

Oman, C. M. and H. J. Weigl. (1989). <u>Postflight vestibulo-ocular reflex changes in space shuttle/spacelab D-1 crew</u>. Aerospace Medical Association.

Shelhamer, M. and L. R. Young. (1990). "Linear acceleration and horizontal eye movements in man", (Abstract) Barany Society, Tokyo, Japan.

Tse, M.I. (1990) "Ocular torsion during linear acceleration in space". SB Thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, June, 1990

Young, L. R. and M. Shelhamer. (1990). "Microgravity enhances the relative contribution of visually-induced motion sensation." Aviat. Space Environ. Med. **61**: 525-30.

## 5. Additional References:

Arrott, A.P. (1985) "Ocular Torsion and Gravitoinertial Force", PhD Thesis in Biomedical Engineering, Massachusetts Institute of Technology, Cambridge, MA, May, 1985

Lichtenberg, B.K. (1979) "Ocular counterrolling induced in humans by horizontal accelerations", PhD thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology. May, 1979

Oman, C. M. (1987). "Spacelab experiments on space motion sickness." (15(1)): 55-66.

Parker, A. J., R. V. Kenyon and L. R. Young. (1985). "Measurement of torsion from multi-temporal images of the eye using digital signal processing techniques." **BME-32(1)**(January): 28-36.