'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

The Multiple Line Scanner Camera Experiment for the Russian Mars 96 Mission: Status Report and Prospects for the Future

G. NEUKUM, J. OBERST, Berlin-Adlershof,
G. SCHWARZ, Oberpfaffenhofen,
J. FLOHRER, I. SEBASTIAN, R. JAUMANN, H. HOFFMANN, U. CARSENTY,
K. EICHENTOPF and R. PISCHEL, Berlin-Adlershof

ABSTRACT

A Russian spacecraft will be launched to Mars in November 1996. Two German multiple line scanners on board, HRSC (High Resolution Stereo Camera) and WAOSS (Wide Angle Optoelectronic Stereo Scanner), will obtain high- and low resolution multiphase color stereo images for geoscientific, photogrammetric, and cartographic studies of our neighbor planet and for studies of its atmosphere. The cameras are currently being radiometrically and geometrically calibrated and undergo thorough performance analyses. Laboratory and outdoor tests of the flight modules indicate that the cameras meet or exceed their design goals. An extensive software package for processing of the data from the raw telemetry formats to the topographic orthomap is currently being developed.

1. INTRODUCTION

1.1 Camera Systems on Mars 96

The exploration of Mars is an important cornerstone of the international space research effort. Currently, space missions to the red planet are being prepared or planned by the United States, the European Space Agency and Russia. Russia's plans include the highly ambitious "Mars 96" project, with the launch of an enhanced Phobos type spacecraft from Baikonur in November, 1996. The space vehicle comprises an orbiter carrying a variety of scientific instruments, two small stations to be deployed onto the Martian surface, and two penetrators for injection into the Martian soil. The orbiter carries more than 20 scientific experiments. Instruments for surface and atmosphere observations include 9 spectrometers, a radiometer, a long-wave radar instrument, and two German stereo scanner systems, the High Resolution Stereo Camera (HRSC) andthe Wide Angle Optoelectronic Stereo Scanner (WAOSS). Both cameras are mounted on an articulated platform, the Argus platform, which provides commandable pointing of its three axes, thermal control and electrical interfaces. Besides the two German cameras, Argus carries a French mapping spectrometer (Omega) and a Russian navigation camera supplying precise pointing information together with the platform gyro system. The instruments are to deliver high resolution, stereo, and multispectral imaging of the Martian surface as well as monitoring of atmospheric phenomena.
The two German cameras form one scientific experiment. An international co-investigator team under the leadership of a principal investigator has been established for this experiment. The team includes 45 scientists representing 27 institutions from 7 countries.

1.2 Science Goals and Instrument Requirements

The main science objectives of HRSC and WAOSS as defined by the Co-Investigator Team are to improve our knowledge and understanding of the shape, structure, and evolution of the planet Mars in terms of geoscience, photogrammetry and cartography, as well as of the structure and dynamics of its atmosphere. Much of these science issues had been addressed by the two highly successful Viking

Orbiter missions in the seventies. Further advanced geoscientific studies planned for Mars 96 include investigations of the:

- nature and origin of geologic features, in particular volcanic, fluvial, periglacial, and eolian deposits,
- chronology and driving forces of sedimentary and erosional processes
- tectonic features and their structural relationships,
- stratigraphy and age determination of geologic surface units,
- crater morphologies and size-frequency distributions,
- physical, chemical, and mineralogical surface material characteristics,
- structure and evolution of the crust and mantle,
- role of water and ice in the history of Mars, and
- characteristics and evolution of polar caps.

Unfortunately, the photogrammetry, cartography, and geodesy aspects were poorly covered by the Viking missions. Mars 96 will cover these aspects on local, regional, and global scales by:

- analysis of the gravity field,
- three-dimensional mapping of the surface of Mars,
- determination of atmospheric cloud heights,
- generation of rectified image maps, and
- refinement of the geodetic control network.

As a result of the general scientific goals, the Mars 96 imaging experiment is designed to provide the following capabilities:

- imaging at high resolution of better than 15 m/pixel,
- stereo imaging of the Martian surface and of atmospheric clouds at various scales,
- multiple areal coverage (to monitor dynamical phenomena),
- multispectral imaging (to study the composition of surface materials),
- multi-phase angle imaging (to study physical properties and weathering states of surface materials), and
- limb sounding.

This has led to the concept of two different multi-sensor instruments: the HRSC principally designed for investigations at local to regional scales panchromatically and in four narrow-band colors, and the WAOSS designed for panchromatic observations of time-dependent phenomena at regional to global scales. The unique advantage over previous imaging experiments from Mars orbit is in the simultaneous stereo, spectral, and photometric coverage and monitoring by the combined operation of the HRSC and the WAOSS sensors.

2. SYSTEM HARDWARE

The science goals mentioned above, and also the Mars 96 mission scenario, had a great impact on the technical design of both HRSC and WAOSS that led to a similar layout of key components within the two cameras. Both cameras had to be designed for observations from an elliptical orbit characterized by varying surface distances, ground track velocities, illumination, and thermal conditions. In particular, the periapsis and apoapsis heights of about 300 km and more than 20 000 km, respectively, suggested in typical Mission scenarios, lead to high ground-track velocities near periapsis and slow

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

spacecraft motion rates near apoapsis. Also, owing to seasonal and orbit drift effects, the solar elevation at periapsis will change from full daylight to dark night during the mission. As a consequence, both cameras have to adapt to the prevailing radiometric and geometric constraints for each individual imaging sequence.
Spacecraft radio link communication with ground stations in the Ukraine and Russia also influences the technical design. This is limited to a few hours per day with the signal run time being up to 20 minutes; therefore, automatic instrument operations with preloaded commanding and intermediate on-board data storage is required. Immediate operator interaction is not possible. Both cameras use on-board real time DCT (Discrete Cosine Transform) compression in order to return a maximum of science data at the limited telemetry rate. Prior to transmission to ground, the compressed image data are stored in a 1 Gbit semiconductor mass memory.
Finally, both instrument designs benefit from the experience gained from previous three-line stereo cameras and hybrid technology electronics. Thus, both cameras use multiple CCD line detectors mounted in parallel. These CCD sensors are installed on focal plate modules which are almost identical for both cameras. Modern high-reliability hybrid technology has permitted the incorporation of miniaturized sensor electronics.

2.1 HRSC

The HRSC instrument was designed as a line scan instrument for local and regional coverage of preselected surface areas. Typically, image strips of more than 300 km length will be collected. These strips will be recorded as overlapping data takes by 9 separate sensors (3 panchromatic stereo sensors, 4 multispectral sensors, and 2 additional photometric sensors). After ground data processing, the image data will yield high resolution, stereo, and thematic map information.
The imaging parameters for each exposure sequence have to be commanded in advance.Owing to the different viewing angles of the individual sensors within the HRSC focal plane, the sensor data have to be activated and deactivated sequentially to obtain overlapping ground coverage. In addition, the sensor exposure times have to be adapted to the varying spacecraft velocities and heights along the elliptical orbit.
The basic technical conception of HRSC is illustrated in Fig. 1 (top) and summarized in Table 1:

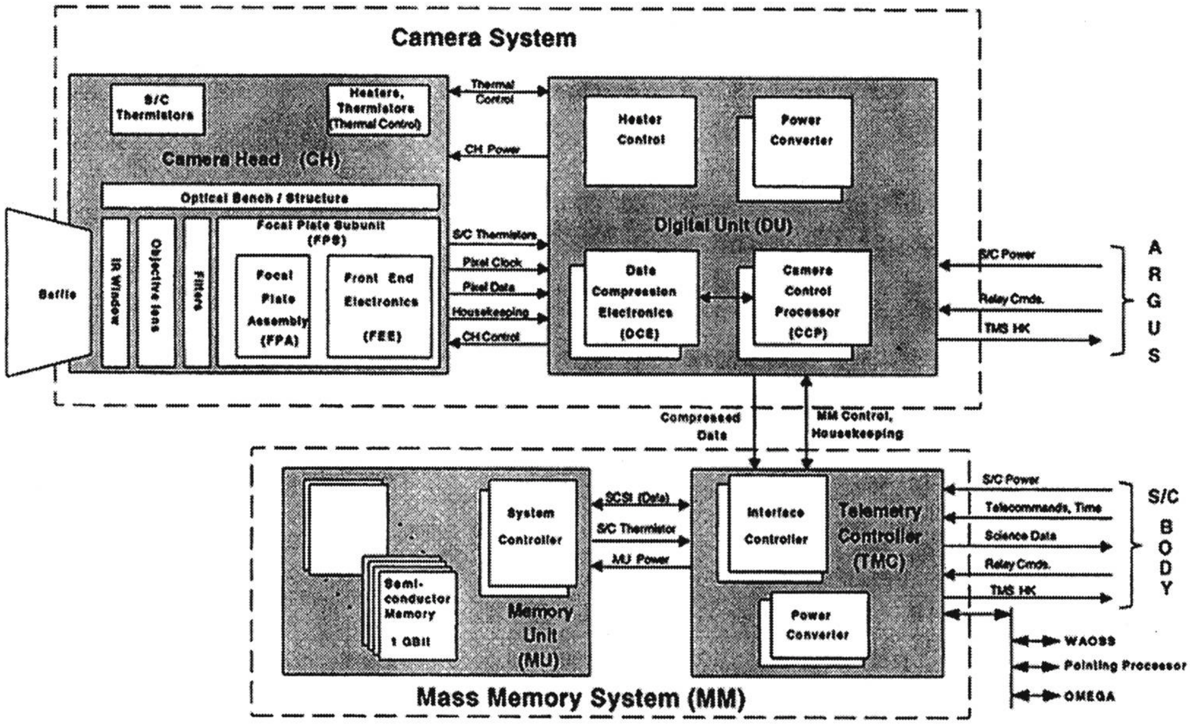
- The camera head comprises a baffle, the optics, separate spectral filters for each CCD line sensor, 3 focal plates carrying a total of 9 CCD line sensors, and the electronics for CCD control and readout.
- The digital unit includes a camera control processor for camera set-up, configuration and monitoring, as well as the electronics for on-line image data compression.
- The separate memory unit offers data storage for both cameras, the Omega instrument and the Argus navigation / gyro system.
- The telemetry controller represents the fourth component of the HRSC experiment. It performs data and command handling, telemetry data formatting for the Argus instruments and Reed Solomon encoding.

The focal plate configuration with the geometric arrangement of the 9 and 3 line sensors of HRSC and WAOSS is depicted in Fig. 2, showing a projection of the CCD lines to the ground from a typical spacecraft altitude of 300 km.

2.2 WAOSS

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

WAOSS was designed for wide angle scanning of the Martian surface and atmosphere. Three CCD line sensors provide panchromatic wide angle stereo coverage. WAOSS permits on-line adaptation



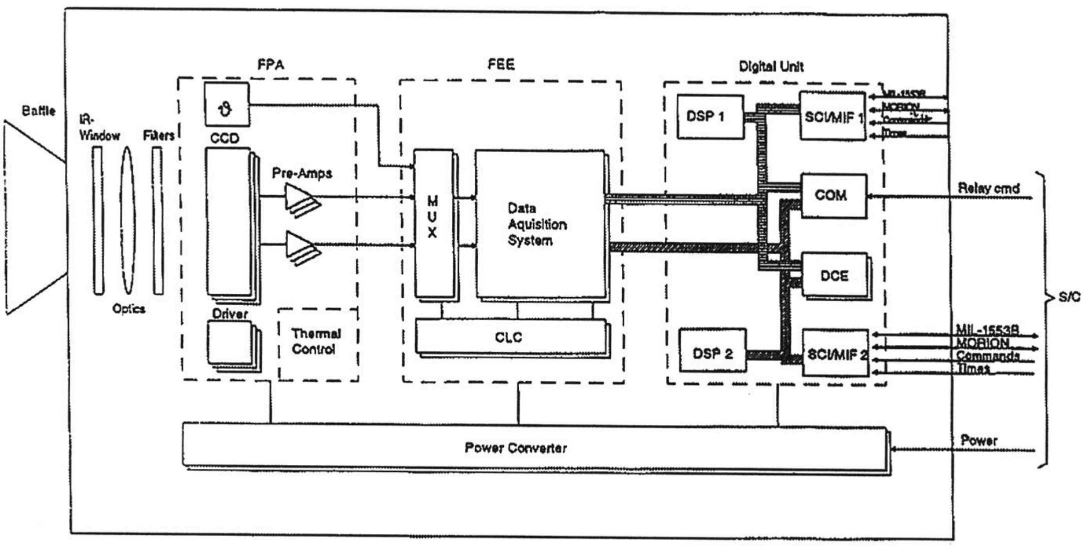


Figure 1: Block diagrams showing the technical conceptions of HRSC (top) and WAOSS (bottom).

	HRSC	**WAOSS**
optics:		
focal length (mm)	175.0	21.7
f number	5.6	5.6
sensors:		
number of sensors	9	3
active pixels/sensor	5184	5184
pixel size	7×7 µm	7×7 µm
field of view (FOV):		
FOV per pixel	8.3 "	67.4 "
cross-track FOV	11.9°	80.0°
stereo angle	18.9°	25.3°
spectral ranges:		
outer stereo channels	675±90 nm	675±85 nm
nadir channel	675±90 nm	580±95 nm
photometry channel	675±90 nm	
multispectral channels near infrared green blue red	 970±45 nm 530±45 nm 440±45 nm 750±20 nm	
radiometric resolution:		
A/D converter bits	10	11
bits entering compression	8	8
min. gain	3.5	automatic signal normalization
max. gain	2528	
operations:		
min. exposure time	2.2 ms	12.5 ms
max. exposure time	54.5 ms	15.0 ms
pixel binning formats	1×1, 2×2, 4×4, 8×8	from 1×1 to 16×16
compression factors (factors that will actually be achieved depend on scenery)	1.1 ... 100	1.1 ... 100
max. data output rate	1.6 MB/s	500 kbits/s

Table 1: Technical parameters of HRSC and WAOSS.

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

of sensor exposure times, signal level normalization, pixel binning and compression rates. The parameters for adaptation control have to be commanded in advance.

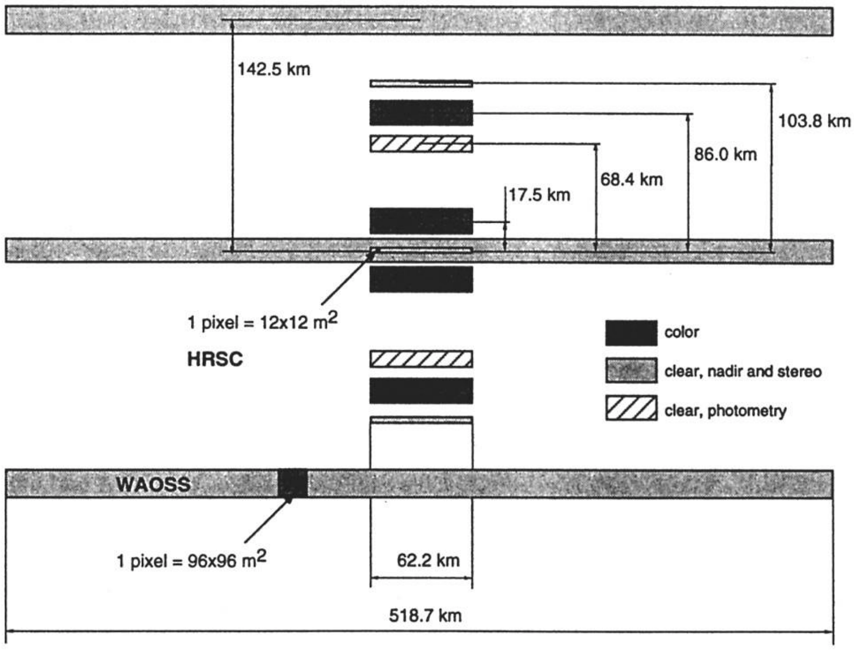


Figure 2: Projection of HRSC and WAOSS CCD lines to the ground from an altitude of 300 km. Note that the width of the CCD lines is not to scale.

In contrast to the multi-box concept of HRSC, WAOSS was conceived as a compact single box instrument with integrated baffle, optics, spectral filters, power converter, 3 CCD line sensors, sensor electronics, and a digital unit for interfacing, data handling, image data preprocessing and compression. A detailed block diagram of WAOSS is shown in Fig. 1 (bottom). Detailed technical parameters of WAOSS in comparison with HRSC are shown in Table 1.

3. CAMERA PERFORMANCE: FIRST RESULTS

3.1 Calibration

The science goals, in particular photogrammetry and spectrophotometry, impose strong requirements on the geometric and radiometric precision of the two camera systems. Therefore, a thorough calibration of the different flight models of the two camera systems was initiated in 1994 and is continuing at the time of writing. The calibrations are being conducted in three stages, the pre-calibration of the Focal Plate Subunit (the sensor electronics alone), the radiometric calibration of the camera head (which includes the optical system), and the geometric calibration of the camera head. For WAOSS, in addition, a complete camera system calibration including power converters and digital unit interfaces was performed.
Calibrations for HRSC are done at the DLR Oberpfaffenhofen facility and the Dornier laboratory in Friedrichshafen (where the HRSC camera is being manufactured). WAOSS, on the other hand, is being calibrated at the DLR Berlin-Adlershof facility.

3.1.1 Radiometric Calibration

During the radiometric pre-calibration of the HRSC Focal Plate Subunit and the WAOSS sensor electronics the following measurements and tests were carried out:

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

- dark signal non uniformity,
- dark signal linearity as a function of exposure time,
- dark signal as a function of gain (CCD signal amplification),
- dark signal dependence on temperature,
- photon response as a function of gain,
- photon response as a function of illumination wavelength (i.e. the spectral response, see Fig. 3),
- photon response linearity as a function of exposure time and light intensity (see Fig. 4),
- photon response non uniformity (flat field measurements; see Fig. 4),
- photon response dependence on temperature,
- signal behavior at CCD saturation, and
- analysis of the influence of the different clocks, signal chains, and sensor positions within the

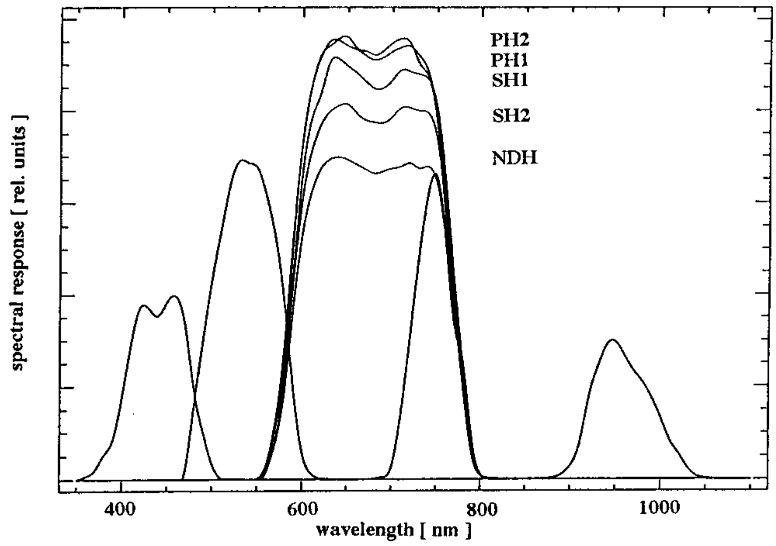


Figure 3: HRSC camera head photon response of the four narrow spectral channels and the five broadband panchromatic stereo (SH1, SH2), nadir (NDH) and photometry channels (PH1, PH2).

multiplexed signals (readout slots).

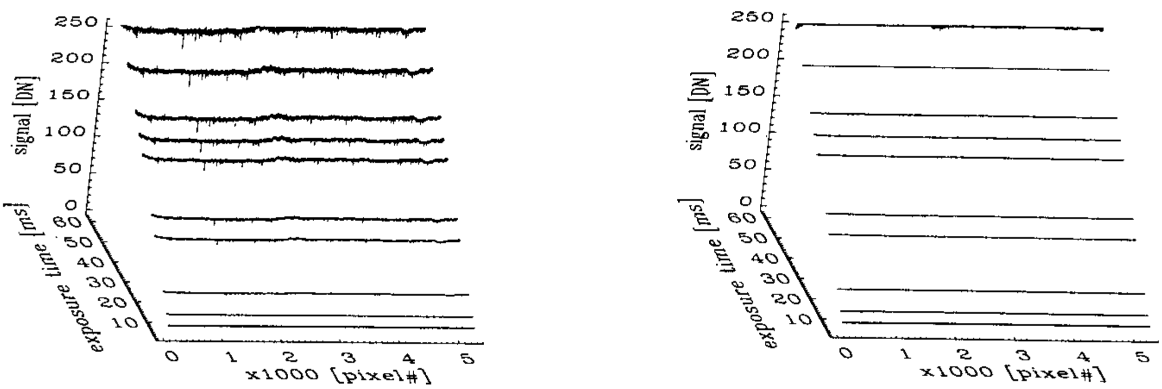


Figure 4: Example of the raw (left) and flatfield corrected (right) CCD signal profiles as a function of pixel number and exposure time.

A preliminary analysis of the extensive measurements suggests that the sensor electronics is fully operational and performing in accordance with all design goals, even at light levels that require high signal amplification. In summary, the typical behavior of a CCD camera in terms of linearity, temperature dependence, flat field, and spectral response could be demonstrated (see Fig.4) for a wide range of CCD signal levels.

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

The main goal of the radiometric camera head calibration was to explore the effects of the optical components added to the Focal Plate Subunit, e.g. on the spectral and flat-field response of the HRSC spectral channels, and to the polarization properties. An additional goal was to verify the results of the pre-calibration. It was found that the camera heads respond to camera commanding in the same way as the sensor electronics did during the pre-calibration.

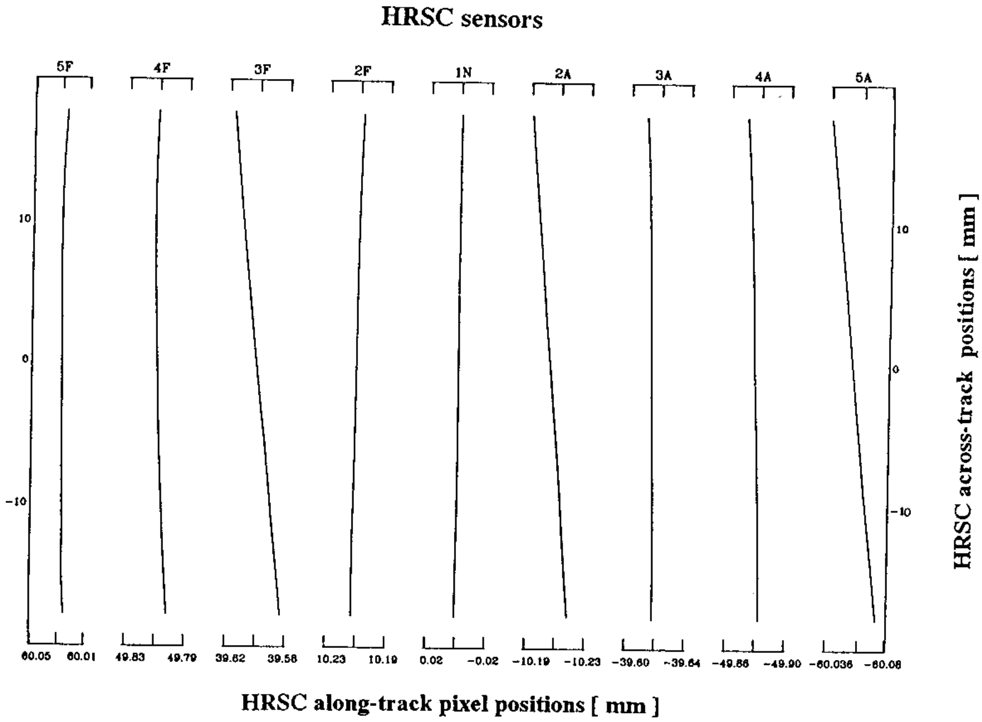


Figure 5: Projection of the view angles of HRSC pixels onto positions on a fictitious focal plane. View angles were measured for pixels on all nine sensors during geometric calibration.

3.1.2 Geometric Calibration

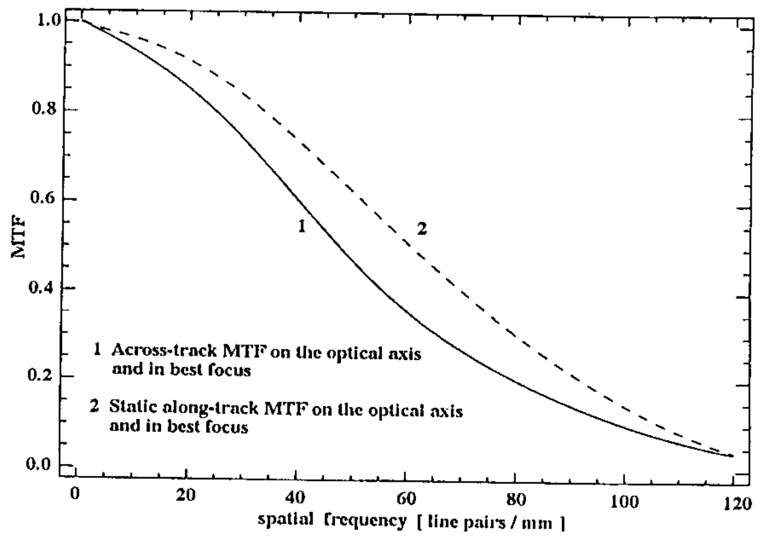


Figure 6: Measured HRSC along-track and across-track camera Modulation Transfer Functions (MTF) near the optical axis. The curves demonstrate the large resolving power of the HRSC. The discrepancy between the two curves mainly results from the asymmetric micro lenses that cover the CCD pixels, from non-uniform pixel sizes, and from transfer phenomena.

The geometric calibration of the HRSC and WAOSS camera heads includes the measurements of the view angles of the light-sensitive pixels of the CCD sensors (see Fig. 5), and the determination of the Point Spread Function (PSF; see Fig. 6) which characterizes the resolving power of the camera.
The Modulation Transfer Functions (MTF) of the optics, calculated from the PSFs, meet the specifications and demonstrates the high quality of the HRSC and WAOSS optics (see Fig.6). A first analysis of the HRSC calibration data suggests that the opto-mechnic camera adjustment is excellent and that the HRSC lens is practically free of distortion. In the vicinity of the optical axis, operation of HRSC is limited by diffraction effects and to the finite CCD pixel sizes only. Detected deviations of the arrangements of CCD pixels from their ideal parallel straight lines mainly reflect the fact that the CCDs are not mounted perfectly in the focal area (see Fig. 5). Calibration shows that stray light levels occuring in the camera are well below the specified requirements. Similar results in agreement with the design specifications were obtained during the WAOSS geometric calibration in Berlin-Adlershof.
Calibration measurements of the flight models for the 1996 launch are expected to be completed by this summer. However, full analysis of the extensive data sets collected during calibration will continue beyond then.

3.2 HRSC Laboratory Tests

Special HRSC tests were conducted in the laboratory at Dornier, Friedrichshafen, from December, 1994 through February, 1995. HRSC test images were obtained of structured and unstructured screen targets using mission-like camera command sets. Targets included a flatfield, grids of various spacings, and a "Siemensstern". Also, images of a Viking Mars scene and a thin section of a rock sample were obtained. The images were available in the form of slides, which were placed in the focus of a collimator and moved perpendicular to the CCD sensors to simulate spacecraft motion.
All light sources were carefully calibrated in order to permit a verification of absolute calibration. In addition, a chopper which could be operated at different frequencies was available to simulate temporal changes in lighting conditions. During test image acquisition, combinations of selected operational parameters, such as exposure time, macropixel format, and compression quality factor were used to explore their effects on image data. The test images allow the analysis of the static and dynamic radiometric and geometric imaging performance of the camera and the identification of critical performance limits of the recorded data and their dependence on commanded operational parameters. In particular, the following camera features and functions will be assessed:

- imaging affected by the different macropixel formats,
- imaging affected by spectral filters of the camera,
- imaging affected by the compression quality factor in comparison with the noncompressed image generated with the same camera command set,
- locally and spectrally dependent Point Spread Function (PSF) and Contrast Transfer Function (CTF) of the camera under simulated flight conditions,
- properties of image data of a slightly defocused camera,
- aliasing effects when sampling periodic structures in dependence of the operational parameters,
- effects of image distortion owing to desynchronization between scan velocity and exposure time, as well as the effect of non-square ground pixel sizes and its correction,
- search for indirect stray light and ghost image phenomena above the 0.5 % limit,
- effects of long-term increase in temperature on CCD signal and camera performance
- camera performance with respect to a temporal change of illumination conditions using the chopper,
- validity of calibration results, such as dark signal, flatfield, and absolute calibration., and

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

Similar extensive tests were performed on the WAOSS camera in the Berlin-Adlershof laboratory. In-depth analyses of all image data obtained in the laboratory are currently under way.

3.3 Outdoor Tests

Observation Site	Site Coordinates	Dates	Viewing Direction
Position 1 (Dornier Campus, helicopter roof)	47°40.25 ' N 09°23.54 ' E Altitude: 425 m	March 2-15, 1995	Azimuth: approx. 175°
Position 2 (Kressbronn)	47°36.66' N 09°35.96' E Altitude: 434 m	March 16-17, 1995	Azimuth: approx. 185°

Table 2: The two camera locations and viewing directions from which stereo images were obtained during the outdoor tests. The cameras scanned an angular range of more than 180°; the given azimuth angles refer to the direction to the Säntis peak.

HRSC/WAOSS outdoor tests were conducted from March 2 through 17, 1995 (Table 2), to verify proper combined operations of both cameras and to test their imaging performance. Both cameras were installed on a turntable which was rotated at a rate that matched the scan rate of the cameras to simulate spacecraft motion. The first images were obtained from the Dornier campus near Friedrichshafen with viewing across Lake Constance and the Swiss Alpes near the Sèntis mountain. Scan rates were also purposely desynchronized to the rotational rate of the turntable (i.e., they were slower or faster than was needed to achieve square pixels) to test the camera response and image quality to this type of commanding. The image data of HRSC and WAOSS were compressed in a way that compression factors of approximately 5 - 8 were normally achieved. However, higher compression rates of up to 40 were also achieved to allow a study of the dependence of data compression on image quality.

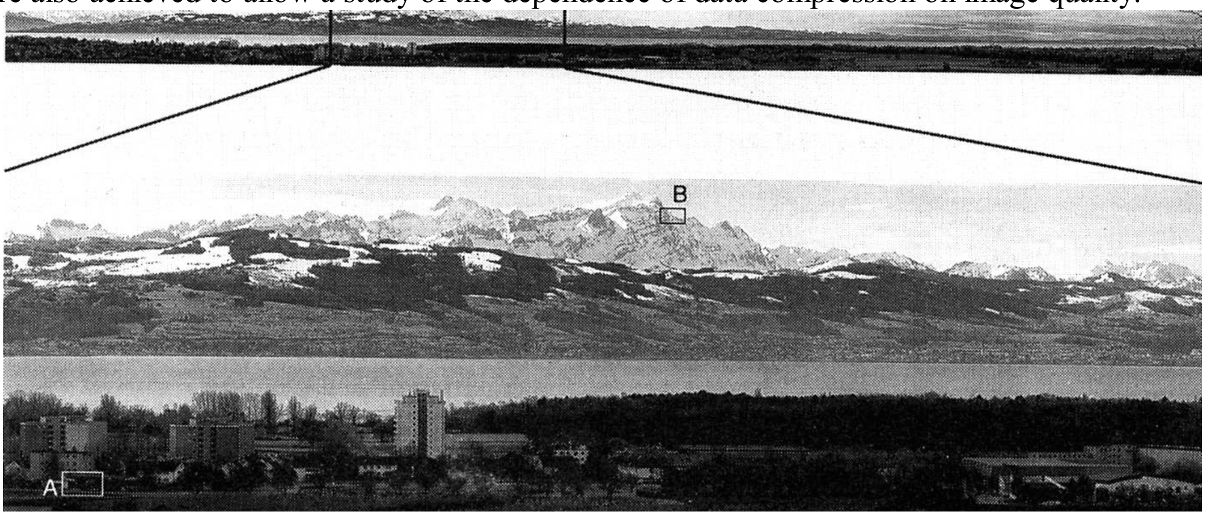


Figure 7: View across the village of Kressbronn (near Friedrichshafen), Lake Constance and the Swiss Alps obtained on March 17, 1995 (top). The image below represents a subset of this long image strip. Details marked "A" and "B" are shown in Figure 8. The image was obtained by the central HRSC channel (which will normally be facing towards nadir during flight operations). The number of sample columns of the image strip at the top is 44,712, the number of lines is 2,448; data from a window of only less than half the width of the scan line was actually collected. Note that a histogram equalization was applied to the image in order to improve the photographic reproduction. The mountain left to the rectangle marked "B" is the Säntis, with an elevation of 2502 m, at a distance of approximately 41 km from the camera site.

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

For HRSC, the images were decalibrated using flat-field correction procedures determined during camera calibration (see Fig. 4). This procedure was found to improve radiometric image quality significantly. In particular, strip-like patterns in the raw data were removed very effectively. For WAOSS, the flat-field decalibration (which, for the wide-angle camera, is normally done within the camera electronics before data compression) was similarly successful. Data from the HRSC spectral channels were combined to near-true-color images in order to perform crude checks on correct color ratios and possible geometric distortions of the CCD lines. More in-depth analyses of image quality are currently under way.

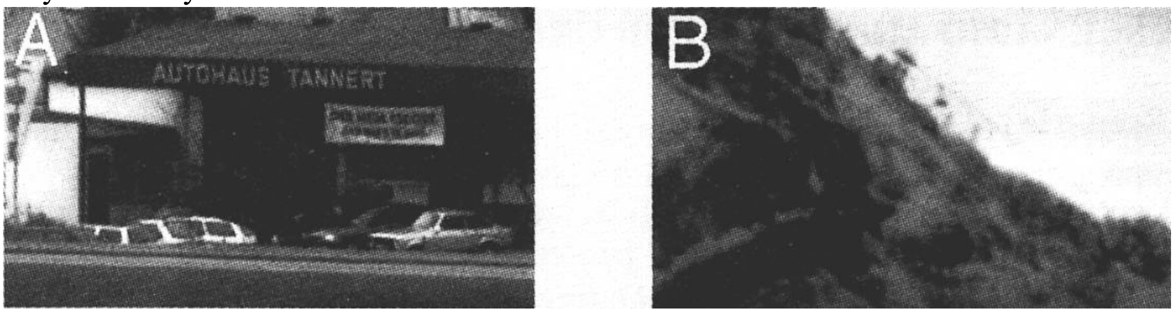


Figure 8: Details "A" (left) and "B" (right) from the overview image in Figure 7. The detail "B" shows the cable car on its way to the Säntis peak. The "ground" pixel size at this approximate range of 41 km is approximately 2 m.

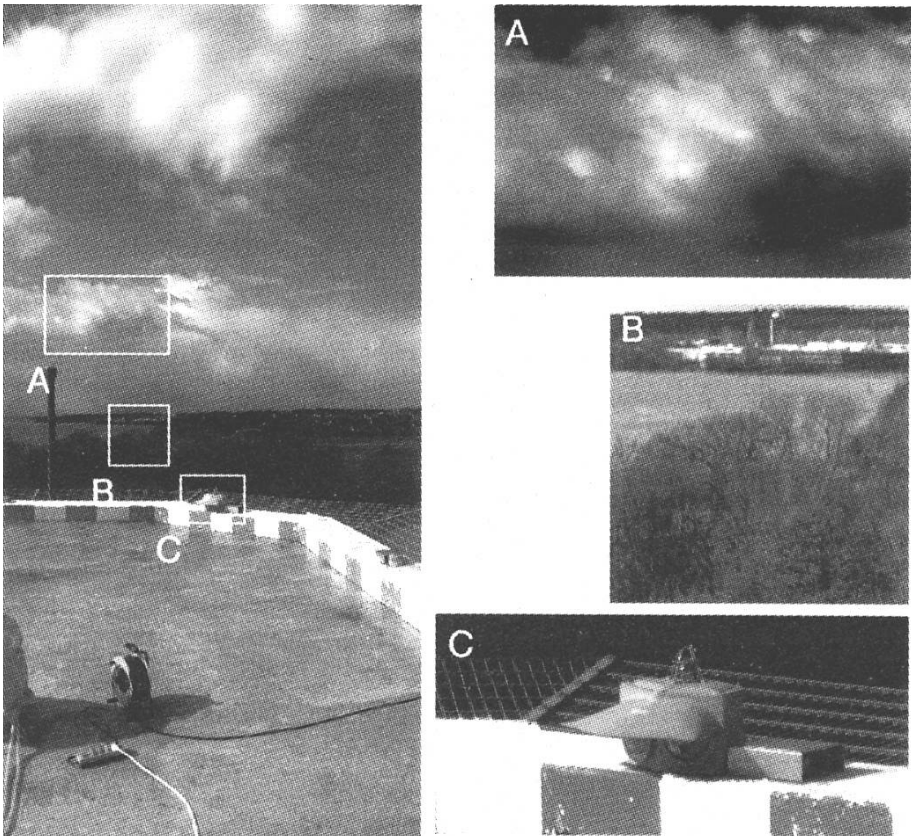


Figure 9: View from the helicopter roof of the Dornier campus near Friedrichshafen obtained with the WAOSS camera. The rectangular details marked "A", "B", and "C" are shown on the right. The size of the image on the left (which constitutes only a small sample of a typical scan) is 896 samples by 451 lines. Note the high radiometric dynamics of the WAOSS image, as seen in detail "A".

The image samples shown here (Figs. 7, 8, and 9) demonstrate the typical acquisition of large-size image strips that reveal great detail in the scenery. Data were also collected from a second location which was offset by approximately 20 km from the first imaging site to obtain stereo coverage of the mountain scenery. Unfortunately, these images were taken a week later, and snow had fallen in the meantime which drastically changed the appearance of the scenery. However, we expect that stereo analysis of these data may still be feasible.
Earlier, the WAOSS camera was successfully tested during several imaging experiments from aircraft. Experiment design and results were discussed separately elsewhere (Terzibaschian and Scheele, 1994).

4. MISSION SCENARIO AND PLANS FOR GROUND DATA PROCESSING

4.1 Mission Scenario

On arrival in December, 1997, the spacecraft will be captured into a highly elliptical orbit around Mars. After release of the small stations and of the penetrators, some orbit correction maneuvers will be performed to reach the final mappping orbit. During the next two Earth years, surface, atmosphere, plasma, and astrophysical investigations will be conducted from this orbit.
For all experiment operations, the spacecraft will be kept inertially fixed with three axes stabilized. One spacecraft axis will be pointed to the Sun, another axis to Canopus. All instrument pointing is achieved by adjustment of the three-axial Argus platform. Although the cameras can be pointed for limb sounding or observations of the Martian moons Phobos and Deimos, most imaging will be conducted with the cameras facing the nadir direction.
Short imaging sessions will be obtained near pericenter, where image resolution will be best. However, image data will be gathered from large distances as well. Data from more than one imaging session can be stored in the mass memory system and will be downloaded once every two days. The expected coverage of the Martian surface by HRSC is 20% at a resolution of better than 15 m/pixel and 50% at a resolution of better than 60 m/pixel. Global HRSC coverage can be achieved at a resolution of better than 150 m/pixel during the nominal spacecraft lifetime of 2 years. Global coverage will be achieved with WAOSS on a regular basis to monitor temporal changes in the appearance of surface and atmosphere.

4.2 Preprocessing and Systematic Data Processing

A total of 20 GByte of raw compressed telemetry data is expected to be received from HRSC and WAOSS. In addition, spacecraft trajectory and camera attitude data will be provided by the Russian mission operation facilities. For processing of this large data volume a comprehensive hardware/software system is currently being developed under the leadership of the DLR Institute of Planetary Exploration in Berlin (Oberst et al., 1994). All software will be portable (i.e. the software runs on different hardware platforms) to run under VICAR (Video Image Control and Retrieval), an image processing system which has been developed by JPL (Jet Propulsion Laboratory) and has been used in previous deep space missions. In Berlin also all the operational data processing will be carried out.
The ground data processing will be conducted in three stages: preprocessing, systematic processing, and scientific processing. The goal of preprocessing is to acquire, decode, and correct the raw data files. During systematic data processing the data will be decompressed, decalibrated, and geometrically corrected. HRSC data will be decompressed using a software package originally developed by Matra Marconi Space, but which has been modified for the requirements of the Mars '96 project. WAOSS data must be decompressed by a dedicated hardware board developed by Prima Graphics.

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

The radiometric decalibration of HRSC data follows procedures designed during the ground calibration of the camera system. In contrast, radiometric decalibration for WAOSS will already be done on board the spacecraft before data compression. During camera operations, sensor temperatures and dark pixel measurements will be obtained simultaneously with the image data, providing important input for the decalibration. An important step in the process is the flat field correction (see Fig 4). Hence, images of a calibration target mounted on the spacecraft will be obtained on a regular basis to detect possible degradation of CCD sensitivity and to update flat field information.
Finally, the raw image data, distorted by varying spacecraft velocity and altitude, camera pointing drift and jitter, as well as changing scan rates and macropixel formats ,will be transformed into defined map projections, i.e. the data are geometrically corrected. Alignment offsets between the platform and the cameras and the misalignments of pixel positions on the camera focal plates, determined during the pre-flight calibration (see Fig. 5), will also be taken into account.

4.3 Scientific Data Processing

Scientific data processing begins from the low-level radiometrically decalibrated images produced by the systematic data processing. In contrast to the earlier processing stages, no operational processing will be performed. Instead, a science software package containing VICAR modules is being developed and will be distributed to all Co-Investigators (see Oberst et al., 1994 for details). This package allows scientists to perform HRSC/WAOSS data analysis at their home institutions at their discretion.

4.3.1 Photogrammetry and Cartography

The first step comprises the photogrammetric restitution of the imagery to improve position and attitude parameters (exterior orientation). For this purpose, conjugate image points will be determined both interactively and automatically by a combination of feature-based and area-based matching techniques using a pyramid strategy (Tang, 1994). The matching software is specifically designed for the Mars 96 imaging experiments. As cycle time, exposure time, and macropixel formats can be adjusted during imaging, this will result in a very complex image file structure.
Conjugate image points and exterior orientation parameters are adjusted by a least squares "bundle adjustment" (Ebner et al., 1993). The procedure will be carried out at local, regional, and global levels involving HRSC and WAOSS data, alone or in combination. Data from overlapping or intersecting imaging sequences will be used for further improvement of geodetic control. An important extension to the existing bundle adjustment program in support of the Mars 96 mission results from the formulation of the collinearity equations in terms of orbit parameters (Montenbruck et al., 1994). This ensures the physically meaningful utilization of orbit information. A priori trajectory and covariance information for the bundle adjustment will be determined by the DLR German Space Operations Center (GSOC) using spacecraft tracking data. An important science goal of the bundle adjustment is to improve existing gravity models (Smith et al., 1993) and ground control network of Mars (Davies and Katayama, 1983; Wu and Schafer, 1984).
The second step comprises the generation of digital elevation models (DEM) and orthoimages. A second matching procedure is used to derive a densely-spaced pattern of conjugate image points, from which a DEM is generated by interpolation. DEM follow-up products include reliefs illuminated from given directions by artificial light sources and perspective views of DEMs with panchromatic or color-image data overlaid.
Topographic maps and thematic maps will be important final products of the scientific data processing (Albertz et al., 1992; 1993). On these maps, (false) color raster image mosaics supplied from photometric and spectrophotometric processing will be combined with vector data, such as elevation contour lines, latitude/longitude grids, names, control points, and lineaments etc. Map designs, formats

and quadrangle schemes in scales of 1:100 000 and 1:200 000 are currently being designed. Map production will be in a fully digital form.

4.3.2 Spectrophotometric Processing

Great emphasis will be placed on spectrophotometric analyses of the radiometrically highly precise HRSC images. As color channel data will be acquired mostly in macropixel formats to reduce the amount of data to be transmitted, the low-resolution color data must be recombined with the high-resolution nadir images by a back-and-forth transformation of color and nadir data from RGB (red, green, blue) into the HSI (hue, saturation, intensity) color space. Furthermore, as color and photometry channel CCD lines have perspective viewing angles that differ from the nadir lines, the data must be geometrically corrected to be comparable with the high-resolution nadir channel.
Panchromatic surface brightness information can be obtained at five distinct HRSC viewing angles, namely by the nadir channel, the two stereo and the two photometry channels (cf. Fig.2). In addition, data from the stereo channels of WAOSS can be included in the analysis. This multiple brightness information will be used to determine coefficients of surface photometric functions by non-linear fitting techniques.
Color data will be used for compositional interpretation of the image data. Likewise, from the variation in surface brightness due to variations in illumination and viewing conditions, the physical properties of the surface material, such as surface roughness and weathering state, can be determined. Spectrophotometry is also an important tool for use in identification of geological units and terrain classification, as an indication of diurnal and seasonal variations in surface deposits, and also for atmospheric studies.

4.4 Data Products and Distribution

The following final data products, estimated to comprise a total of 3.4 TByte of data, will be archived and prepared for distribution:

- compressed, unmerged raw data, including housekeeping information,
- decompressed, merged data (i.e., data received at different ground stations and different telemetry frames are combined into single consistent files),
- radiometrically corrected data (based on in-flight and laboratory calibration),
- geometrically corrected data (based on laboratory geometric calibration, as well as reconstructed navigation and attitude information), including navigation and auxiliary files, and
- DEMs (Digital Terrain Models), orthoimages, topographic and thematic maps, photometrically and multispectrally processed data, combined HRSC and WAOSS scenes.

The scientific data products (DEMs, orthoimages, etc.) will be provided only for selected HRSC/WAOSS scenes.
Scientists will be able to access a data catalog remotely via a query program to view information about available HRSC/WAOSS data, and to request data of interest from the DLR Regional Planetary Image Facility (RPIF) located at the DLR Institute of Planetary Exploration, Berlin. All final data products will be stored on CD-ROMs for distribution.
Data formats of all HRSC/WAOSS data products will follow PDS (Planetary Data System) standards in terms of logical and physical data structures, documentation, and file naming conventions. The pre-master CD-WORM will be produced in-house and will be sent to the PDS Geoscience Node at the Washington University in St. Louis, Missouri (USA) where mass production of deliverable CD-ROMs

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

will be organized. After the end of a proprietary phase of 18 months, all data will be available via PDS and NASA's RPIF system to the entire science community.

5. SUMMARY AND FUTURE PROSPECTS

The hardware components for the two German stereo scanner experiments HRSC and WAOSS, designed for the Mars 96 mission, are currently being calibrated and tested and were found to be fully operational and to meet all design goals. The experiment comprises a full ground data system which is currently being developed and tested. This system includes all processing steps from the raw telemetry formats to the calibrated and corrected image data on CD-ROMs or the printed topographic and thematic map.
The development of light-weight imaging devices based on the multiple line-scanning concept bears an enormous potential for future planetary and Earth-oriented space missions. The major advantage of scanners over frame CCDs is the possibility to obtain larger-size images and in combination of the different imaging capabilities, such as high resolution, stereo, and color (as it is realized for the HRSC instrument). The currently designed deep space missions call for light-weight sensors to reduce launch costs and mission complexity.
Ongoing studies of imaging instruments for future missions have shown, that only little modifications of the HRSC-design are required to reduce the weight of the system drastically without sacrifices in performance (Tab. 3).

	Moon	**Moon, Mars**	**Earth I**	**Earth II**	**Earth III**
Optics	single	single	single	triple	triple
Focal Length (mm)	176	176	661	1 x 661 2 x 289	1 x 661 2 x 356
Number of CCD-Lines	9	9	6	9	9
Imaging Capabilities	triple stereo 6 colors	triple stereo 6 colors	high resol. 5 colors	triple stereo 6 colors	triple stereo 6 colors
Pixel/Line	5200	5200	9000	3×9000 6×5200	$3 \times 12,000$ 6×5200
pixel size (µm)	7	7	8	8 7	6.5 7
data compression	online DCT 2...20	offline .DCT- Wavelet	offline DCT- Wavelet	offline DCT- Wavelet	offline/online Wavelet
performance at 400km height:					
spatial resolution (m/pixel)	16	16	5	5 10	4 8
swath width (km)	83	83	45	45 52	48 42
mass (kg)	15	7	20	25	30

Table 3: Multiple line scanner designs based on the HRSC under study for future planetary and Earth-oriented space missions.

A number of future missions to Mars, Moon, and Earth orbit are currently under study by NASA, ESA, DARA, and industry. Several candidate missions have been identified (Tab. 4) that would offer potential for great science return when equipped with scanners. Participation in these missions seems mandatory, as, especially with the HRSC-based design, Germany now has the opportunity of providing high-performance imaging on space mission to explore the planets as well as Earth.

Mission	Target	Type	Imaging Tasks	Status/ Remarks
Mars Surveyor	Mars	orbiter	global coverage with high resolution (16m), stereo, and color	NASA mission; launch 1998
Intermarsnet	Mars	lander and orbiter	very high resolution with stereo and color	currently under study by ESA
MORO	Moon	orbiter	global coverage with high resolution (4m), stereo and color	currently under study by ESA
LEDA	Moon	lander	high resolution stereo imaging of landing site and surrounding areas (South Pole area)	currently under study by ESA
ADLEX	Earth	Int'nal Space Station	stereo and color imaging	ESA Phase A study
OFFEQ 3	Earth	satellite (Israel)	stereo and color imaging	industry project
REGIUS	Earth	small satellite	high resolution (5m) and color imaging	DARA Phase A study
Erdsat	Earth	small satellite	high resolution (<4m), stereo (?) and color	industry project

Table 4: Overview of future candidate missions to carry the multiple line scanners HRSC and WAOSS.

6. ACKNOWLEDGEMENTS

We wish to thank all contributors to the HRSC/WAOSS experiment. The HRSC/WAOSS experiment is funded by DARA (Deutsche Agentur für Raumfahrtangelegenheiten) and DLR (Deutsche Forschungsanstalt für Luft- und Raumfahrt) and supported by the Management Services of DLR, Cologne. The HRSC is manufactured by Daimler-Benz Aerospace / Dornier. WAOSS is developed and manufactured by the DLR Institute of Space Sensors, Berlin-Adlershof. The Technical University Munich (TUM), Chair for Photogrammetry and Remote Sensing, the Technical University Berlin (TUB), Chair for Photogrammetry and Cartography, University of the Armed Forces (UBW), Institute for Photogrammetry and Cartography, the Max-Planck Institute for Aeronomy (MPAe), and the Jet Propulsion Laboratory (JPL), Pasadena, California (USA) provide extensive scientific expertise and software support to the experiment. The Mars 96 project and the Argus complex for the cameras is under the leadership of the Space Research Institute (IKI), Moscow.

7. REFERENCES

Albertz, J., F. Scholten, H. Ebner, C. Heipke, and G. Neukum (1992): The Camera Experiments HRSC and WAOSS on the Mars 94 Mission. Internat. Archives of Photogrammetry and Remote Sensing, Commission I, Volume 29, Part B1, pp. 130-137, Washington D.C., (USA).

'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

Albertz, J.; Ebner, H.; Neukum, G. (1993): Die Kamera-Experimente HRSC und WAOSS der Mission Mars 94/96. Photogrammetric Week '93 Fritsch/Hobbie (Eds.), pp. 121-134, Stuttgart (Germany).

Davies, M. E. and F. Y. Katayama (1983): The 1982 Control Network of Mars. J. Geophys. Res., 88, pp. 7503-7504.

Ebner, H, T. Ohlhof, L. Tang (1993): Photogrammetric restitution of Mars 94 three-line scanner imagery. SPIE-Conference State-of-the-Art Mapping, 13-15 April 1993, pp. 19-32, Orlando, Florida (USA).

Greeley, R. and R. M. Batson (1990): Planetary Mapping. Cambridge University Press, Cambridge New York, 296 pages.

Montenbruck, O., E. Gill, and T. Ohlhof (1994): A combined approach for Mars-94 orbit determination and photogrammetric bundle adjustment. German Aerospace Research and Establishment (DLR).

Oberst, J, B. Giese, T. Roatsch, K. Eichentopf, W. Tost, A. Harris, R. Reulke, R. Jaumann, G. Neukum (1994): Mars '94/96 Pushbroom Cameras: Plans for Ground Data Processing and Analysis. Proceedings of the Symposium "Mapping and Geographic Information Systems", ISPRS, Vol 30, 4, pp. 533-540, Athens, Georgia (USA).

Smith, D. E., F. J. Lerch, R. S. Nerem, M. T. Zuber, G. B. Patel, S. K. Fricke, and F. G. Lemoine (1993): An Improved Gravity Model for Mars: Goddard Mars Model 1. J. Geophys. Res., Vol. 98, No. E11, pp. 20,871-20,889.

Tang L. (1994): Automatic Determination of Conjugate Points in Multi Images of Different Resolutions for Photogrammetric Processing within the Mars'94/96 Mapping Experiment. Proceedings of the Symposium "Mapping and Geographic Information Systems", ISPRS, Vol 30, 4, pp.541-547, Athens, Georgia (USA).

Terzibaschian, T., and M. Scheele (1994): Attitude and positioning measurement systems used in the airborne testing of the original Mars Mission Wide Angle Optoelectronic Stereo Scanner WAOSS, ISPRS, pp. 47-55, München.

Wu, S. S. C. and F. J. Schafer (1984): Mars control network. Technical Papers of the 50th Annual Meeting of the American Society of Photogrammetry and Remote Sensing, Washington D.C., March 11-16, Vol. 2, pp. 456-463.