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MOMS: A contribution to high resolution multispectral and stereoscopic earth observation from space

PETER SEIGE, Oberpfaffenhofen

ABSTRACT

MOMS-02/D2 is, as a continuation of MOMS-01, a development for digital mapping of the Earth's surface from space. The camera was flown on-board the second German Spacelab Mission D2 which was launched on April 26, 1993. During the mission 4.5 hours of data were recorded which is equivalent to coverage of approximately 7 mio m^2.
The special characteristic of this camera is the combination of high resolution panchromatic images for 3-dimensional geometric information with multispectral images for thematic applications.
With this concept MOMS-02 is fundamentally different from all existing remote sensing systems and thus pursues new and independent goals.

1. BACKGROUND OF MOMS-02

MOMS-02/D2 is a development of MOMS-01, which has already been successfully tested on two spaceflights. The verification of the modular optics concept, as well as the testing of the optoelectronic CCD sensors, were priorities of the first two missions, on the Space Shuttle flights STS 7 and STS 11, in 1983 and 1984, respectively. For this purpose, MOMS-01 was equipped with only two spectral modules. The spectral ranges of the two channels were between 575 and 625 nm, and between 825 and 975 nm, respectively. The ground pixel size, for an orbit altitude of about 300 km, amounted to 20 x 20 m^2, with a swath width of 140 km.
The two spaceflight missions fully proved the performance capabilities of the modular and optoelectronic MOMS-01 concept. Thus, the conditions for the development of an even more advanced system were met.

2. MOMS-02 CONCEPT AND TECHNICAL FEATURES

The technical features of the MOMS-02 camera are oriented toward the requirements of the photogrammetric and thematic sciences, as well as on the limiting technical conditions of the D2 mission. The system layout is chiefly specified through such requirements as

- three-fold stereo imagery
- along-track stereo imagery
- high resolution imagery
- multispectral imaging
- combinations of stereo and multispectral imaging

Figure 1 shows a schematic representation of the MOMS-02 optical concept. In order to be able to fulfil the different user requirements a modular concept, which was already successfully proven by MOMS-01, was selected. The system consists of five lenses, three of which are intended for the stereoscopic images, and the other two for the multispectral images. The central lens, with a focal length of 660 mm, forms the core of the camera system. It makes possible the high resolution imagery with a ground pixel size of 4.5 x 4.5 m^2. In order to attain a sufficient swath width with such high resolution, two linear sensors are optically joined to each other in the focal plane. In

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connection with the central high resolution lens, there are two other stereo lenses, each with a focal length of 237.2 mm. Because of their pitch of +21.4° and -21.4°, respectively, relative to the direction of flight, three-fold stereoscopic imagery is achieved. The focal length of these lenses was so chosen, that there is an integral relationship between the ground pixel sizes seen by the high resolution channel and the two inclined channels of 1:3.

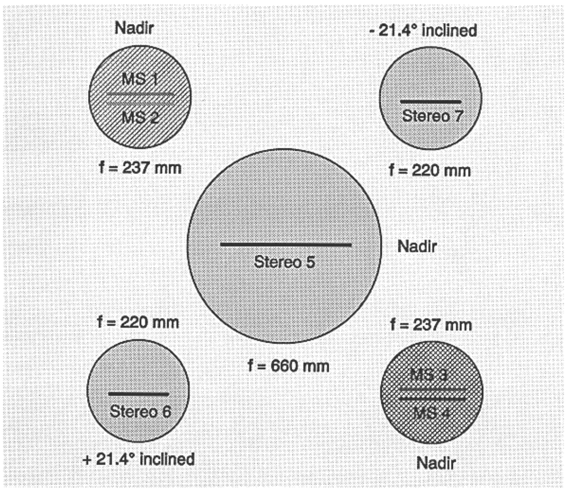

Figure 1: MOMS-02 optical concept.

In addition, two other lenses, each with a focal length of 220 mm, enable the multispectral imaging of a total of four channels. In order to achieve this, there are two sensors in the focal plane of each lens, together with their corresponding filters. In order to ease the image data analysis, the ratio of the ground pixel size of the high resolution channel with that of these multispectral channels is selected to be 1:3.

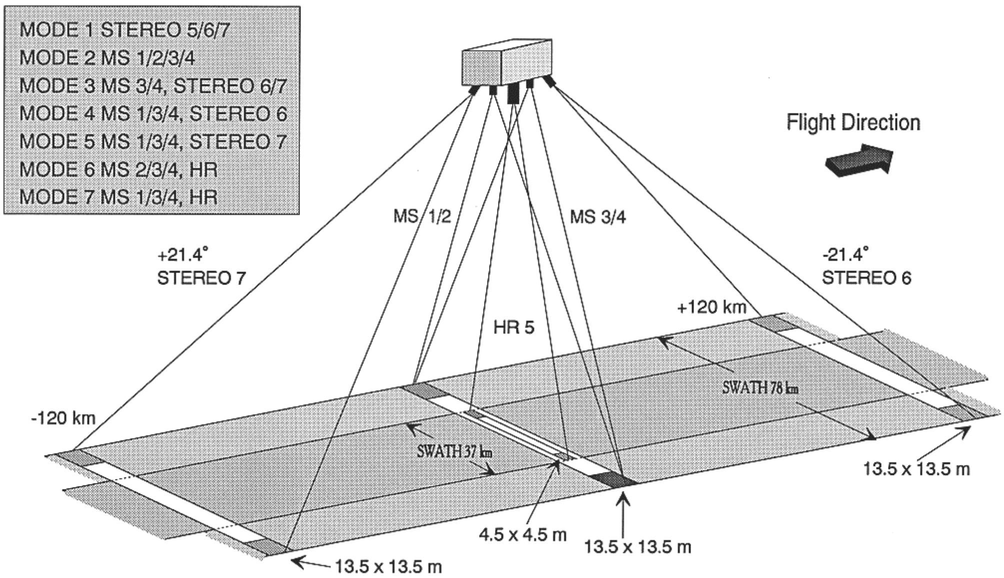

Figure 2: MOMS-02 imaging geometry.

Figure 2 shows the total MOMS-02 imaging geometry, and the ground track resulting from it. The swath width for the high resolution channel can be as much as 37 km, depending on the recording

mode, and for the other channels, as wide as 78 km. These values are relative to a nominal orbit altitude of 296 km. Because of the viewing angle of 21.4° in the two outer stereo channels, the image swath on the earth's surface for these channels is separated from the swath of the nadir channels by about 120 km.
Figure 3 shows the relation of pixel sizes of comparable instruments. It can be easily evaluated that the MOMS camera is superior to all existing remote sensing systems so far flown in space.

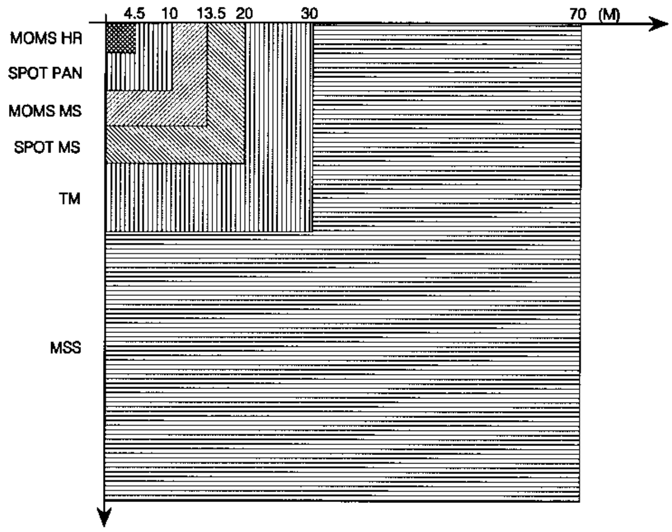

Figure 3: Comparison of pixel sizes of MOMS, SPOT and Landsat sensors.

Table 1. lists the most important optical parameters of the MOMS-02 camera where all geometric data are related to a nominal flight altitude of 296 km. The center wavelengths of the seven channels are distributed over a range between 472 nm and 790 nm. The corresponding bandwidths, of the multispectral channels, vary between 35 nm and 65 nm. The stereo channels all cover the same panchromatic region, a bandwidth of 240 nm with a center wavelength of 640 nm was selected.

Channel	Mode	Orientation	Band Width	Ground Pixel	Swath Width
1	M/S	Nadir	440 - 505 nm	13.5 x 13.5 m	78 / 43 km
2	M/S	Nadir	530 - 575 nm	13.5 x 13.5 m	78 / 43 km
3	M/S	Nadir	645 - 680 nm	13.5 x 13.5 m	78 / 43 km
4	M/S	Nadir	770 - 810 nm	13.5 x 13.5 m	78 / 43 km
5	HR	Nadir	520 - 760 nm	4.5 x 4.5 m	37 / 27 km
6	Stereo	+ 21.4°	520 - 760 nm	13.5 x 13.5 m	78 / 43 km
7	Stereo	- 21.4°	520 - 760 nm	13.5 x 13.5 m	78 / 43 km

Table 1: MOMS-02 performance charcteristics.

The MOMS-02 stereo imaging principle is illustrated in Figure 4. The three viewing angles already discussed make it possible to image a strip A on the earth's surface, at three different times, and with the three different viewing angles. The fact that the three images are recorded with a lag time of about 20 seconds makes it difficult to correlate the images, because of the intervening movement of the platform. In order to later be able to model, and thus compensate for these movements, other appropriate supplementary data must be available. These are for one, the position data given by TDRSS and ground tracking, and for another, the attitude data delivered by the Shuttle navigation system. The latter are supposed to be recorded directly with the MOMS-02 image data during the flight. The development of digital terrain models will be supported by an appropriate orbit modelling taking attitude and orbit data into account.

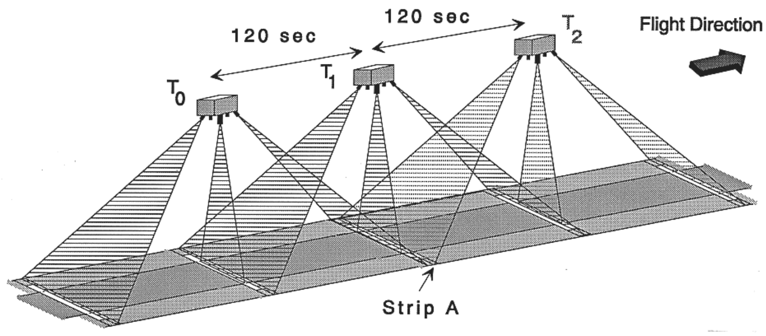

Figure 4: Stereo imaging principle.

The very high data rate of the MOMS-02 channels, gives rise to certain operational limitations during the mission. The maximum data recording rate of the on-board magnetic tape recorder is 100 Mbit/sec, which means that all the channels cannot be operated simultaneously. In order to be able to manage the high data rates, data compression is necessary, especially in the high resolution channel, which is compressed from the original 8 to 6 bits. It was determined that the compression procedure would not impair the ability to interpret the stereo imagery. The multispectral channels can be recorded without compression, with the full radiometric resolution of 8 bits. The adaptation of the data take parameters to the current illumination conditions occurs by a switching of the electronic gain factors by means of ground commanding.

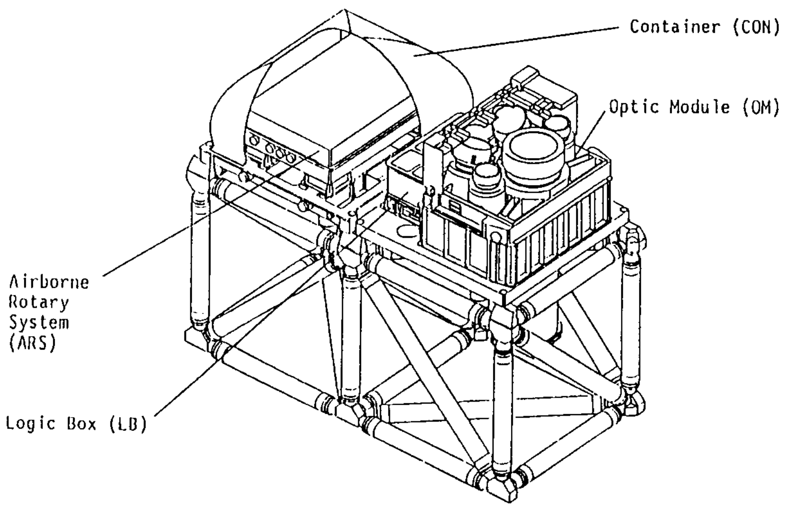

Figure 5: Schematics of MOMS hardware concept.

The tape recorder allows a maximum recording time of 5.5 hours, corresponding to a data capacity of 2.5 x 10^{12} bits. With this recording capacity, 8-10 million km^2 can be covered, depending on the combination of operational modes used. The entire system manufactured by DASA, German Aerospace is mounted on the Unique Support Structure (USS) bridge, and meets free space

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conditions. Because the bridge is not accessible during the flight, the magnetic tape cannot be changed. Figure 5 shows a schematics of the MOMS-02 hardware indicating the major components of the system.

3. D2 MISSION

MOMS-02 is the only earth remote sensing system on the D2 mission, and therefore must be integrated into the limiting operating conditions of the other, primarily materials sciences, experiments. The orbit inclination has been reduced from the original 57° to 28.5° so that for this mission, mainly equatorial regions will be covered.
Figure 6 shows typical orbit paths, as well as the borders of the possible coverage area. The boxed-in areas are the regions of primary interest for the scientists participating in the mission. For comparison the MIR-PRIRODA paths are shown with an inclination of 51.6° (see section 6 outlook).

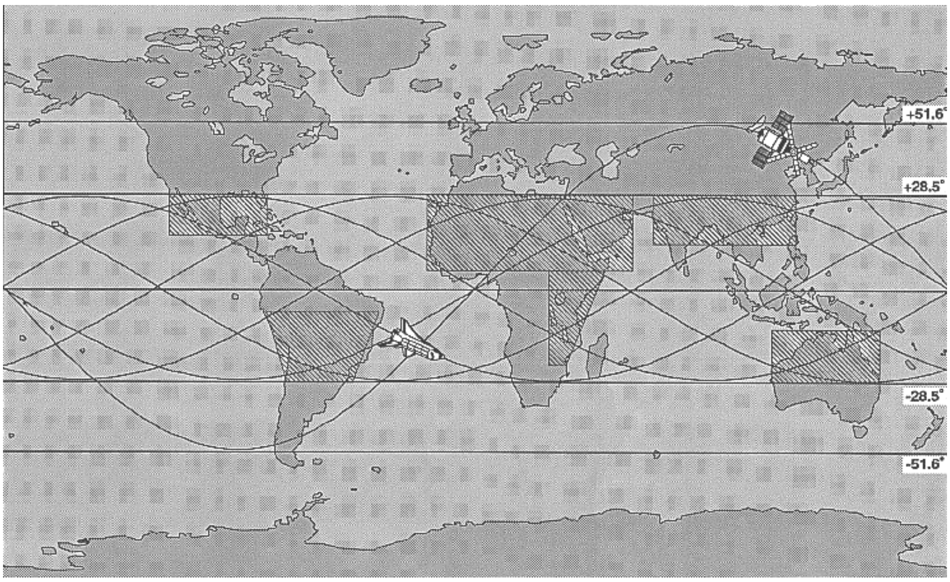

Figure 6: MOMS-02/D2 test areas of main interest.

After several delays, MOMS-02 was launched on April 26, 1993 at 15:52 GMT onboard the Space Shuttle Mission STS 55. Fig. 7 shows the mission operation scenario at the DLR MSCC at Oberpfaffenhofen. The major task of the MOMS science team was to finally select the precise MOMS target areas and along with that properly set the gain factors for the various channels. Prior to the mission there were extensive discussions with the D2 timeline responsables which resulted in a preselection of test sites for MOMS, which on the one hand satisfied the scientific requirements of the MOMS team and on the other hand fit into the various boundary conditions of the D2 mission given mainly by the large number of experiments to be served.
Additionally the MOMS science team was supported by simulation calculations also performed during the mission preparation phase which allowed a proper MOMS gain setting, taking parameters such as the MOMS camera parameters, sun elevation, atmospheric conditions and various types of albedos into account.
During the mission phase the final target selection was based on precise orbit calculations which were performed on the basis of the most up to date Shuttle state vectors. Probably the most important parameter for a final data take decision was the actual weather situation in the pre-selected target area. For this purpose DLR installed a link to the NASA Earth Observation

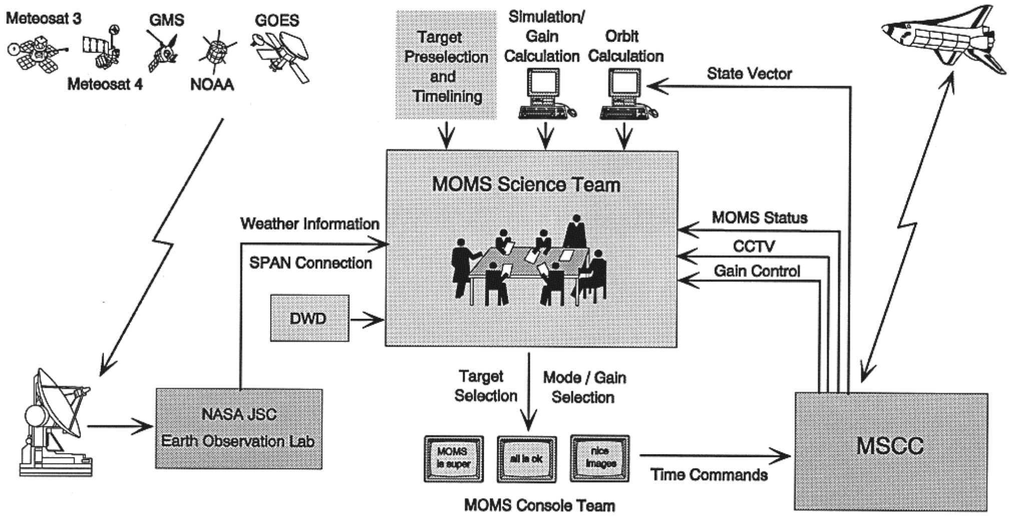

Figure 7: Mission operation scenario.

Laboratory at JSC Houston where actual information from all important weather satellites such as METEOSAT 3 for the North- and South America region, METEOSAT 4 for the African region, GMS for the Asian and Australian area, GOES for the Central American area and NOAA for the Indian region were available. Fig. 8 shows as an example a METEOSAT 3 image showing South America with the predicted Shuttle orbits indicating the potential MOMS data take areas along with the present weather situation. Additionally the German Weather service in Offenbach (Deutscher Wetterdienst) provided METEOSAT 4 images from the African region.

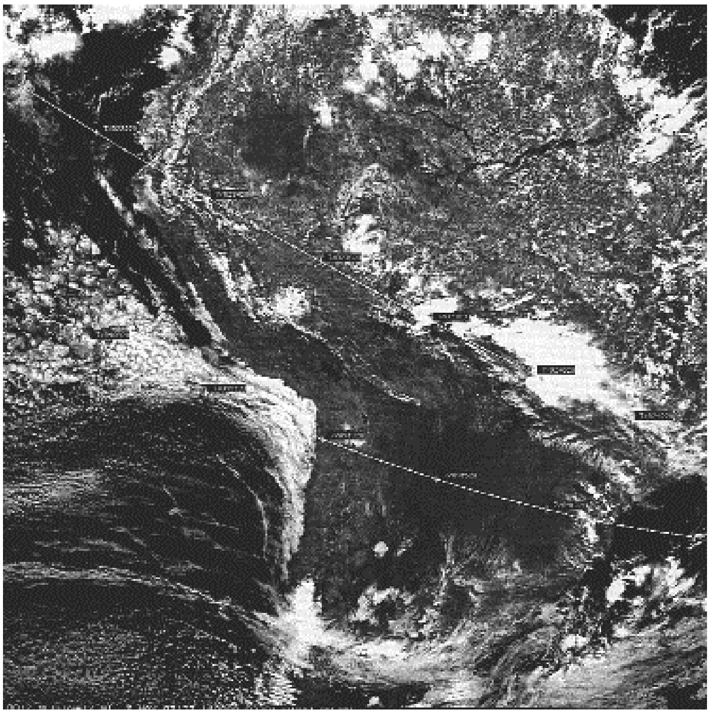

Figure 8: METEOSAT 3 weather satellite image from South America during MOMS mission.

Due to the high data rate MOMS images could not be transmitted directly to ground during the mission. In order to be able to control the status of the experiment a number of housekeeping data

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were transmitted which showed parameters such as various temperatures, tape recorder pressure, operational status etc. The proper gain setting and in some limitation the imaging quality could be controlled by real time TV transmissions. For this purpose the MOMS resolution was intentionally degraded by a factor of 8 in line direction and the same in flight direction and subsequently fed into the Shuttle TV channel for transmission. Due to the lack of continuous coverage and the TV requirements of other experiments this could only be performed at selected target areas. Nevertheless it was a very valuable tool for controlling the MOMS performance during flight.
Fig. 9 shows an overview of the MOMS data takes during the ten days mission. In total 4.5 hours of MOMS data could be recorded during the entire mission corresponding to an area of about 7 mio km^2. Not all of the tape capacity of 5.5 hours was available for imaging data since prior to each data take (and sometimes also after the data take) calibration data were also recorded on tape.

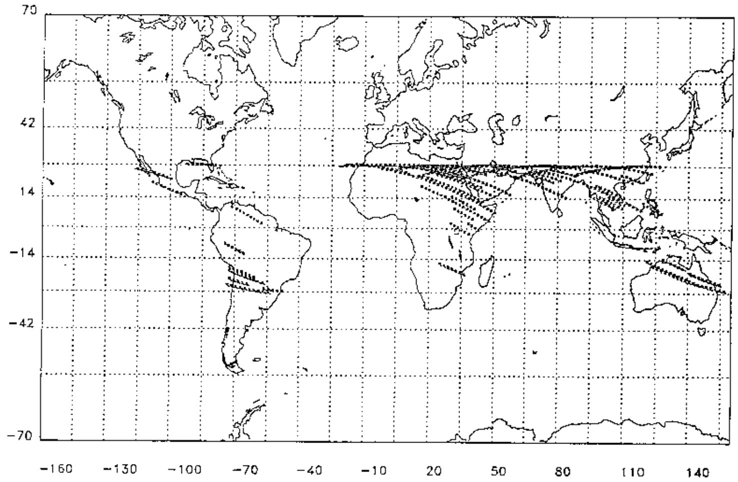

Figure 9: Overwiew of MOMS STS 55 data takes.

Fig. 10 shows in some more detail the MOMS ground tracks in the African/Arabian area. It can be recognized that in some areas such as Northern Africa there is a dense coverage resulting in some side overlaps of the strips. Additionally in some cases orbit crossings could be achieved which is of high importance for the photogrammetric data evaluation.

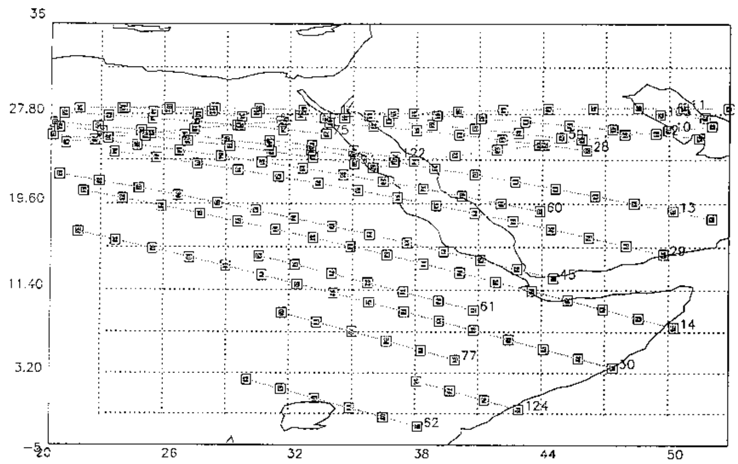

Figure 10: Detailed display of MOMS ground tracks over Northern Africa/Arabia.

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4. DATA CONCEPT

During the ten day flight of MOMS-02/D2, a total of about 2.5 x 10^{12} bits of data, from the operational modes previously described, were recorded on high density magnetic tape. The recorded tape was brought back to Germany at the beginning of July for processing.

Figure 11 shows an overview of the data processing concept developed for MOMS-02/D2. To get a quick overview of the raw data, a Quicklook data set was planned. This image data set had a strongly reduced resolution, reduced by a factor of 5 for both the rows and columns. Because of the large quantity of data, it is planned to store the Quicklook data on an intermediate optical disk. From this optical disk, the Quicklook images can be readied for single CCT copies, and/or produced on film. The Quicklook images are to be used, for one, to check the quality of the recorded images, and, for another, to select especially interesting images for further processing. The Quicklook images also represent the groundwork for the preparation of a data catalogue, which, for later users, will streamline the selection process of images of interest.

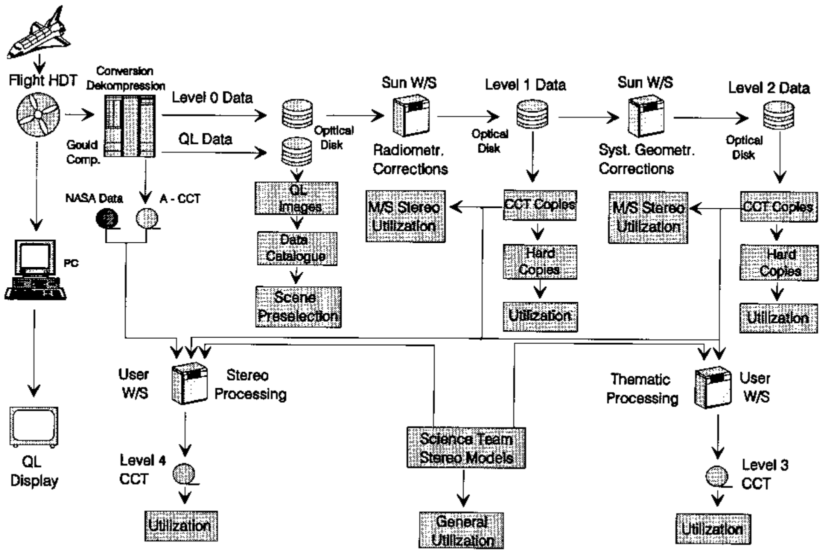

Figure 11: MOMS-02 ground data processing steps.

In the next step the conversion from HDT into computer compatible data takes place. This process will run on a specially adapted Gould computer. Within this process, the decompression of the data, which was compressed on-board, will take place, in order to restore the original 8 bit format in the three stereo channels. The converted data will also be stored on an optical disk, in order to simplify the manageability of the great quantity of data. The data format is compatible with the pertinent DLR standards, since the subsequent image data sets are proposed to be processed on the DLR systems. From there, the data can be distributed to the users.

Since the MOMS-02/D2 flight attitude data derived from the Shuttle navigation system is recorded along with the image data, the plan is to generate a separate CCT with the data conversion, which will contain the Shuttle attitude data. This so called A-CCT will serve as the input data for later modelling of the Shuttle flight attitude. Additionally a NASA tape containing orbit data will be used for orbit modelling which is an important supplementary input for digital terrain modelling.

Just as the first data conversion takes place on a specially adapted computer, all the subsequent processing steps are planned for so-called workstations. This concept offers the advantage of increased processing speed, which is critical in light of the large quantity of MOMS data. In addition, this concept offers the possibility of more parallel processing. The standardization of the

computing concept with respect to routine preparation of the image data, and with respect to the users, simplifies software exchange and to possible editing problems.
The Level 1 data comes about in the framework of the first systematic correction step, whereby the data which had already been radiometrically corrected on board, would undergo any necessary fine radiometric correction on the ground. The data storage will be, as in the previous steps, on optical disk. With the Level 1 data, usable data is available to the users. In the next step, systematic geometric corrections, necessitated by the curvature of the earth and the earth's rotation, will be made. The storage and distribution of these systematically corrected Level 2 data conform with the previously described procedures. The project goal is to have the data conversion and all systematic correction completed within a period of one half year after the flight.
Figure 11 illustrates the general use of the various level data products. Because the Level 0 data is of such limited value, the use of the data will be concentrated on the radiometrically and/or geometrically corrected data. In many areas of thematic application, these data are directly usable in image and CCT form.
In the next higher analysis level, for the examination of atmospheric influences or the specification of altitude dependent phenomena, there will be, along with the systematically corrected data, stereo analysis models, drawn upon for the production of level 3 data. The production of high accuracy digital terrain models constitutes the core of the MOMS-02/D2 data analysis. Within the framework of preparing for the D2 flight, the necessary software packages will be developed by the Science Team, and will be tested using MEOSS aircraft flight data.
An integrated stereo work site is planned to be built within the DLR Institute for Optoelectronics, where all the software packages from the participating scientists will be integrated. In addition to supporting the specialized work of the participating institutions, this work site will enable users to use all the software packages developed for the project. The Level 4 data products, which in addition to the stereo models, contain the integrated supplementary orbit and Shuttle attitude data, represent the scientifically most demanding application of the MOMS-02/D2 data.

5. SCIENTIFIC GOALS

The MOMS-02 is designed to improve the performance of existing systems basically in three ways:

- digital imagery of higher geometric resolution and geometric accuracy compared to other systems,
- high performance along track stereo capability, to be operated in the panchromatic mode alone or in various combinations with the multispectral channels,
- optimized layout of four multispectral channels with narrow band widths for various thematic applications.

The system is to be compared especially with the Thematic Mapper (USA), the SPOT (France), and the film camera systems Large Format Camera (USA), Metric Camera (Federal Republic of Germany), and KFA-1000 (USSR).
The MOMS-02 experiment is generally to be seen in the light of recent trends for improving the earth observation systems. On the MS side there is a tendency for higher geometric resolution and accuracy, in combination with more specific layout of the MS channels, and with additional support by three-dimensional information on relief, slope, and exposition.
On the photogrammetric side there is the general tendency for establishing an autonomous high-precision system with the particular capability for deriving from space digital terrain models of high accuracy (< 5 m) and for obtaining high resolution topographic information in order to make

topographic mapping and geographic information systems genuine spaceborne products on accepted levels of professional standards.
As far as data processing and application is concerned the overall goal of the experiment is the development and application of a complete digital photogrammetric system and the combination of high precision geometric performance with multispectral information, which means the integration of photogrammetric and remote sensing methods. The system is later to be extended and applied operationally on a polar platform.
The photogrammetric tasks to be solved can be grouped in three main packages which may be called:

- geometric restitution,
- digital image matching and image measurement,
- topographic information extraction.

This means the solution of the following detailed tasks:

1. The general task is the development of methods and programmes for mastering the linear array image geometry and of deriving precise three-dimensional geometric object information.
2. The image geometry of the stereo-array camera system poses particular problems, which can only be solved by modelling the orbit most precisely. Therefore assessment of the flight path by using all available tracking data and on-board data of inertial systems in essential. Also extended methodical and accuracy investigations about the restoration of the flight and image geometry will be required.
3. Methods are to be developed and tested for the automatic derivation of high-precision digital terrain models from the digital stereo-image data. Vertical accuracy of better than 5 m is aimed at.
4. The high resolution given by 4.5 m pixel size is the basis for investigating the potential for extracting topographic information of sufficient resolution and accuracy for producing topographic maps and for establishing or updating geographic information systems. It is to be tested in particular whether established quality standards will be met.
5. Extracting topographic information may still be done by human operators. In order to meet future operational requirements it will be essential to develop and evaluate automated methods by making use of digital image processing techniques and of pattern recognition concepts, up to knowledge based and artificial intelligence methods.
6. A very specified field of investigation concerns the combination and the mutual support of photogrammetric and of thematic information. It is particularly the question to what extent the thematic classification can be improved by the stereo-information and the high resolution and high accuracy of the panchromatic data. On the other hand it is a point of investigation whether thematic information from the MS data can improve the extraction and the interpretation of topographic information from the stereo-channels.

Figure 12 shows the MOMS project organization along with the participating science team. It includes experienced scientists from German University Institutes where four of them are related to photogrammetry and three are geoscience institutes concentrated on thematic data evaluation. All of them are closely cooperating with the DLR Institute for Optoelectronics where most attention is given to the combination of multispectral and stereo data.
Generally, the STEREO-MOMS mission marks a basic step towards a new level of quality from the point of view of photogrammetry as well as with respect to instrumentation and evaluation methods. For future operational space missions new standards are given.

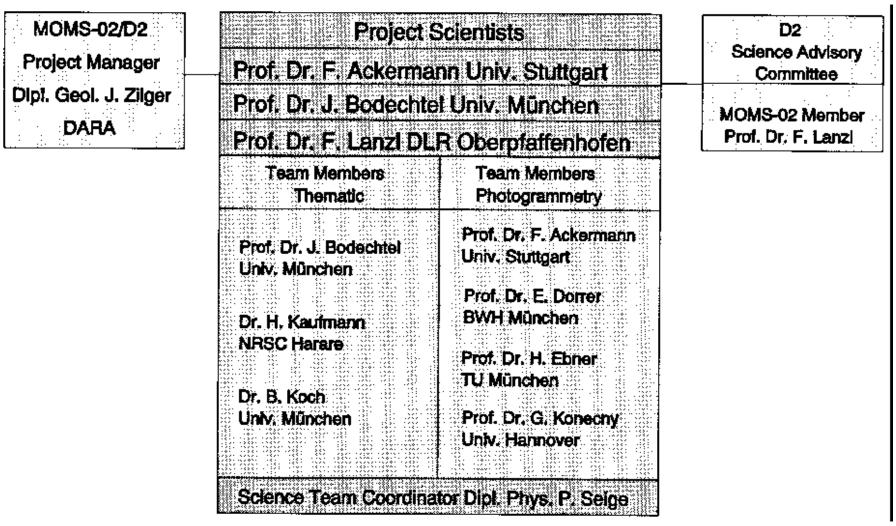

Figure 12: MOMS Science team and project organization.

6. OUTLOOK

MOMS-02 is of experimental nature, with regard to both the technical performance and the scientific goals. It is a challenge, however, in view of a number of key items the successful tests of which will serve as guideline for the future development.

During the last two years the DLR Institute for Optoelectronics established intensive contacts with the Russian Academy of Sciences in Moscow resulting in a flight opportunity of the MOMS-02 camera on the MIR-PRIRODA module in early 1995 with an envisaged mission time of one year. After completion of the D2 mission MOMS will be refurbished and adapted to the PRIRODA environment. Additionally a navigation package will be included consisting of a high precision gyro and a GPS system in order to provide the necessary position and attitude data for supporting a high precision data evaluation mainly for extracting digital terrain models. Scientifically the major advantages of the PRIRODA missions compared with D2 are:

- Long term observation capability (one year)
- Coverage of higher latitudes between 51.6°
- Multisensor approach in combination with the complex set of earth observation experiments onboard of the PRIRODA module

It is expected that the requirements for digital cameras in space will still increase during the next decade, concerning pixel size, resolution, and accuracy. On the other hand, the integration of geometric/photogrammetric and thematic information is expected to proceed much further. It has to go along with great efforts for further automation. The MOMS-02 experiment will give answers and results and will be crucial for pursuing further lines of development for operational optical observation and survey of the earth from space.

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