BIRD - A DLR SMALL SATELLITE MISSION FOR THE INVESTIGATION OF HOT SPOTS, VEGETATION AND CLOUDS

K. Briess, H. Jahn, H. P. Röser
DLR, Institut für Weltraumsensorik, Rudower Chaussee 5
D-12489 Berlin, Germany

Commission I, Working Group 5

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ABSTRACT

The paper describes the German small satellite mission „BIRD" (Bi-spectral Infrared Detection). This DLR mission is dedicated to hot spot detection and investigation from space. Starting from the scientific objectives the requirements on the sensor system are derived. A dedicated two-channel cooled infrared sensor system is developed for hot spot detection and investigation from space. It is combined with a two-channel VIS/NIR sensor system for special questions of the remote sensing of vegetation. This sensor system is controlled by an advanced payload data handling system with an 1 Gbit on-board memory. A technological experiment for the thematic on-board data processing by means of a neural network is an additional element of the payload data handling system. A speciality of this mission consists in the constraint to implement this payload on a micro satellite suitable for a piggyback launch. So the launch is not a main cost driver as for other small satellite missions with dedicated launchers. The mass of the complete satellite including payload and launch adapter has to be less than 100kg. The paper describes not only the payload but also the satellite, the mission conception and the strict design-to-cost philosophy. The BIRD mission is now in the Phase C/D and will be launched in the year 2000.

KURZFASSUNG

Der Beitrag beschreibt die deutsche Kleinsatellitenmission „BIRD" (Bi-spectral Infrared Detection). Diese DLR-Mission ist auf die Detektion und Untersuchung heißer Punktquellen (hot spots) aus dem Weltraum spezialisiert. Von den wissenschaftlichen Zielen ausgehend werden die Anforderungen an das Sensorsystem abgeleitet. Für die Detektion und Untersuchung von hot spots wird ein dediziertes Zweikanal-Infrarotsensorsystem entwickelt. Für spezielle Fragestellungen der Vegetationsfernerkundung wird es mit einem Zweikananal-VIS/NIR-System kombiniert. Das Sensorsystem wird von einem Nutzlastdatensystem mit einem 1Gbit-Massenspeicher, realisiert in modernster Technologie, gesteuert. Ein zusätzliches Element des Borddatenverarbeitungssystems besteht in einem technologischen Experiment zur thematischen an-Bord-Datenverarbeitung mit Hilfe eines Neuronalen Netzes. Eine Besonderheit der Mission besteht in der Randbedingung, die Nutzlast auf einen Mikrosatelliten zu implementieren, der für einen piggyback-Start geeignet ist. Dadurch ist der Raketenstart nicht der Hauptkostentreiber wie bei anderen Kleinsatellitenmissionen mit dedizierten Raketenstarts. Die Masse des kompletten Satelliten einschließlich Nutzlast und Startadapter muß kleiner als 100kg. Der Beitrag beschreibt nicht nur die Nutzlast sondern auch den Satelliten, das Missionskonzept und die strenge kostenorientierte Entwurfsphilosophie. Die BIRD-Mission befindet sich jetzt in der Phase C/D und wird im Jahr 2000 gestartet.

1. INTRODUCTION

For occurrences as forest and vegetation fires, volcanic activity or burning oil spills and coal seam a dedicated space instrumentation does not exist up to now. Other space sensors are used for the observation of these events but they have some drawbacks because they are not designed for the hot spot investigation. But a certain number of important questions about the status of the natural environment on Earth and the global and local changes are related to hot spot events.

The DLR together with the German space company OHB Bremen has studied a dedicated small satellite mission for fire detection and evaluation from space (Jahn et al., 1996) in the year 1994. The FIRES mission was designed following a design-to-science philosophy as a pre-cursor mission for an operational small satellite system consisting of few satellites dedicated to hot spot detection and investigation. But because of the lack of funding these activities were stopped at the end of Phase A in 1995.

Besides this mission proposal few other missions with a new generation of infrared array sensors are proposed which are appropriate to the tasks above. These sensors consist of cooled infrared arrays with a high need on electric power for cooling. The proposed French mission IRSUTE (Becker et al., 1996) was designed in design-to-science philosophy and was stopped after the pre-phase A. The FUEGO proposal (Spain and other) (Gonzalo, 1996) describes a more service-oriented small satellite mission for fire detection in the Mediterranean region. The missions above are characterized by 3axis stabilized satellites with a mass in the order of 300kg and by a dedicated launch strategy. The dedicated launch strategy is one of the main cost drivers of these missions. In difference to these mission proposals the DLR small satellite mission called BIRD follows strictly a design-to-cost philosophy. That means that the feasibility of a low-cost piggyback launch strategy drives the development of the satellite and the mission conception. The mission is not optimized related to the objectives but related to the cost-performance relationship. The orbit is not only selected by scientific requirements but also by the launch opportunity in the proposed launch year.

2. MISSION OBJECTIVES

2.1 Scientific Objectives

The scientific objectives of the BIRD mission are close related to these from the FIRES mission proposal (Jahn et al., 1996), but also with some essential differences. The main scientific objective consists in the recognition and investigation of vegetation fires from space. Some arguments from (Jahn et al., 1996) should be repeated at this place.

Today we have a minor part of natural vegetation fires (caused by lightning, volcanism and so on) and a major part of fires caused by man. These fires have an important impact on the destruction of (primary) vegetation (connected with problems of erosion), on global and regional climatology and atmospheric pollution, on the reduction of the number of species living on earth (bio-diversity), and last not least directly on human lives. The regional and global importance of vegetation fires for the environment was emphasized and investigated in detail in many papers and books, see e.g. (Crutzen and Goldammer, 1993), (Goldammer, 1990), (Goldammer, 1993), (Goldammer, 1994), (Levine, 1991). But up to now a dedicated sensor system for fire investigation from space does not exist.

The biggest periodically burnt vegetation areas are the tropical and sub-tropical savannas. With a periodicity of 1-2 years an area of approximately $0.5\text{-}1*10^9$ ha is burnt down on average every year. But the exact extent of the burnt area is not known because of a lack of monitoring.

In the tropical rain forests the net deforestation rate per year caused by fires is approximately $2*10^7$ ha, whereas the fire area is considerably larger.

Fires in the Mediterranean region devastate shrubs and forests on an area of $6*10^5$ ha per year, whereas in the "Mediterranean" regions of North America $4*10^6$ ha are involved. As in the tropical forest, fires in these regions lead to a degradation of the vegetation.

The boreal forests, which are the largest woodland of the earth, have an area of $1.2*10^9$ ha. The areas burnt down yearly are approximately $1*10^7$ ha in Siberia and $3\text{-}5*10^6$ ha in Canada and Alaska. Especially in the CIS states, there are *radioactively contaminated forests* with an area of $7*10^6$ ha.

Besides the destruction of unique primary vegetation and many other species, the fire impact on the atmosphere is of particular importance. About 20% of the antropogenic emissions of carbon dioxide are caused by vegetation fires. Other greenhouse gases (e.g. methane, N_2O), toxic and other gases (e.g. CO, NO_x, SO_2, HCN), and aerosols (black carbon) are released in a substantial amount. Photochemical reactions lead to the generation of ozone in the troposphere. The smog produced by fires in tropical regions is comparable with the smog generated in the industrial countries under special weather conditions. The molestation of people by smoke in huge regions (e.g. the whole central Brazil, South-East Asia) is tremendous (toxic and cancerogenous substances are carried by the smoke particles) and often leads to the interruption of the aircraft traffic. SO_2 generated by fires can produce acid rain which damages the forests further.

A fundamental problem connected with the fires is the global carbon cycle. Carbon is released by fires as gases (CO_2, CO, CH_4,...) and aerosols (soot), and is distributed as ashes in the environment. In the global carbon balance is a uncertainty of about 1 Gt of carbon per year, which has to be explained. This huge amount in principle can be produced by fires, but the verification of this hypothesis needs precise and comprehensive measurements which can only be provided by remote sensing methods. Correct measurements of the fire extent and temperatures, of the ejected smoke volume, of the burnt biomass, and of the released amount of various gases are necessary.

The carbon balance together with other fire generated phenomena (such as the generation of condensation nuclei by smoke aerosols) is responsible for the broadly discussed climatic changes which are expected. The net released CO_2 leads to an enhancement of the greenhouse effect, whereas fire generated condensation nuclei lead to the formation of clouds which reflect the sunlight resulting in a temperature decrease. Smoke clouds absorb the sunlight in higher layers of the atmosphere resulting in a cooling of the lower layers. Important is also the generation of black carbon (pure C, soot, charcoal), because pure C can be stored in the ground unaltered for millions of years leading to a real carbon sink. This way fires can cause a real decrease of carbon in the global carbon cycle. All these fundamental problems cannot be solved at present because of the lack of sufficient measurements.

A special problem in this connection is the proportion of CO to CO_2, which are released by fires. In hot fires (flaming combustion, high oxygen supply) a low amount of CO is produced, whereas in smoldering fires big amounts of CO (and other hydrocarbons) are generated. Therefore the measurement of the fire temperature is very important. Because the released CO_2 amount can be estimated from the burnt biomass (which in turn can be estimated from the fire parameters (temperature and extent) and the burnt area), a certain (coarse) assessment of the CO/CO_2-ratio is possible by fire parameter (and vegetation change) measurements. Of course, direct measurements of gas emissions from fires, e.g. by special infrared remote CO- or CO_2-sensors, would be extremely valuable.

Because of the ecological necessity to investigate the impact of fire on the local and global environment a sensor system for fire investigation from space on a global scale should be established. Such a dedicated sensor system should give support to the international fire-ecological research in the investigation of vegetation fires. It should supplement the ground based and aircraft systems which are used now. Despite these scientific activities it is an important task of the near future to develop fire monitoring and alert systems *and* fire fighting infrastructures in large regions of the world (together with other methods of fire prevention such as education).

The scientific investigation from space of hot spots caused by volcanoes is a very interesting topic for the community of volcanologists. But the results of a scientific investigation of volcanic monitoring from space are also very interesting for a civil disaster monitoring and disaster prevention program.

About 50 volcanoes per year endanger their environment and the population. It is estimated that in the year 2000 about 500 Mio people are endangered by volcanic eruptions. The impact of volcanic eruption clouds on the air traffic and on the climate are strong. But there are no systems in space dedicated to the investigation of volcanoes. The proposed mission should contribute to the

- monitoring of an ongoing eruption,
- long-term monitoring of young lava-covered areas,
- contribute to the investigation of possible pre-cursors of volcanic eruptions.

Another group of scientific questions are connected with the assessment of the burned area. Not only the estimation of the burned area is an important fire-ecological question but also the assessment of the re-growth of vegetation on burned areas or of their degradation. But with a dedicated vegetation sensor also additional questions of the inventory of forests, savannas and other vegetation could be considered. Questions of the early diagnosis of vegetation condition and changes are important not only for the local users but also for the scientific community investigating climatic models and changes. These objectives require a very precise determination of some parameters for characterizing the surface cover like the Normalized Difference Vegetation Index NDVI, the Leaf Area Index LAI and others. New methods to reduce the atmospheric distortions of the signals and to improve the accuracy of the LAI and other parameters are required to feed the radiation transfer models for a more precise information about the photosynthesis or the early diagnosis of vegetation changes.

Further the detection and investigation of clouds is an important scientific objective of the BIRD mission. As it is mentioned above the discrimination of smoke clouds from water clouds and the investigation of the smoke clouds caused by vegetation fires in combination with the fire investigation can support the estimation of the impact of fires on atmosphere and on the local and global environment.

But also the dedicated investigation of water clouds at local points of intersection with data of meteorological satellites can give some new information about the quality of the cloud evaluation in certain regions which are derived from data of meteorological satellites with a coarser spatial resolution.

2.2. Technological Objectives

Besides the scientific objectives the mission meets also technological and scientific-methodical objectives. A group of technological objectives are related to the implementation, test and demonstration of a new class of infrared sensor systems in orbit suitable for small satellites. These new infrared sensor systems are characterized by using of detectors with a high detectivity which are arranged as a staggered line array. They have to be cooled down to a temperature of 80K by means of a cooling machine (e.g. a Stirling cooler). One technological main objective of the BIRD consists the design, the implementation and the operations of such new infrared sensor system for small satellite applications.
On the other hand the implementation of the cooled infrared arrays on a small satellite (total mass: less than 100kg) is close connected with a number of challenging technological questions on the spacecraft bus design (power supply, thermal conditioning, pointing stability, pixel co-registration and so on). A very important technological experiment of the BIRD mission consists in the on-board classification (see (Halle, 1996)). The implementation and test of a thematic on-board data processing by means of a of a neural network classificator in orbit is opens the door for future operational Earth watch satellite systems with a very short response time.

2.3. Scientific-Methodical Objectives

With the BIRD mission some innovative scientific methods and algorithms will be investigated. One of the main scientific-methodical objectives is related to the analysis of the temperature and the extent of a hot spot within a sub-pixel. The separation of the temperatures between the hot spot and the background will be investigated with two different methods: the Dozier-Method (Dozier, 1981) and the Multi-Sensor Multi-Resolution Technique (Zukov and Oertel, 1995). Other methodical objectives are connected with the investigation of vegetation by means of the Vegetation Index 3 (VI3) and the comparison with the well known Normalized Differential Vegetation Index NDVI.

2.4. Summary of the Mission Objectives, Operational Requirements and Mission Constraints

A summary of the primary mission objectives is given in tab.1.

Tab.1: Mission objectives of BIRD

	BIRD - mission objectives
primary objectives	1. test of a new generation of infrared array sensors adapted to Earth remote sensing objectives by means of small satellites 2. detection and scientific investigation of hot spots (forest fires, volcanic activities, burning oil wells or coal seams)
secondary objectives	3. thematic on-board data processing (test of a neural network classificator in orbit) 4. more precise information about leaf mass and photosynthesis for the early diagnosis of vegetation condition and changes 5. real time discrimination between smoke and water clouds

The **operational requirements** are characterized by

- operational lifetime of 1 year,
- duty cycles of 10min over land regions mainly,
- on-board processing of data,
- raw scientific data downlink to a dedicated payload ground station (Neustrelitz),
- short mission or payload command access at the next possible uplink,
- possibility of direct payload control by scientific users and experiment team.

The constraints for the mission design are described in tab. 2. The main constraint and the design driver for the mission consists in the piggyback launch strategy. That assures a low-cost approach. The mission design follows strictly a design-to-cost philosophy.

But the piggyback launch strategy has the drawback that the orbit can not be optimized related to the functional requirements and the sensor systems. The orbit follows from the appropriate piggyback opportunity. For the BIRD mission a sun-synchronous orbit fulfills the scientific requirements best, but an orbit with an inclination of i ≥ 53° should be acceptable, too.

Tab.2: Constraints for the mission design

	constraints
development time	≤ 3 years
lifetime	1 year in orbit
launch constraints	low-cost launch by piggy-back launch, price range: ca. 6000US$/kg
Instruments	WAOSS + infrared sensors
mission type	micro satellite mission with scientific and technological objectives
cooperation	cooperation between different DLR institutes and the Technical Univ. of Berlin
environmental conditions	space conditions within the van-Allen-Belt, next maximum Sun spot in the year 2001, Dose (Si): < 7krad (behind 2mm Al, spherical geometry)
interfaces	compatibility of the scientific downlink to the main data receiving ground station in Neustrelitz
funding	DLR

3. THE SCIENTIFIC PAYLOAD

Starting from the scientific and technological objectives the requirements on the sensor system can be defined. Tab.3 gives an overview over the different scientific requirements on the payload system. The payload is designed to fulfill the scientific requirements under the conditions of a small satellite in a lower Earth orbit. It consists of the following main parts:

- the Wide-Angle Optoelectronic Stereo Scanner WAOSS
- the two channel infrared sensor system for hot spot recognition
- the payload data handling with a mass memory
- a neural network classificator.

Fig. 1 shows the structure of the smart multi-sensor system.

The Wide Angle Optoelectronic Stereo Scanner WAOSS is designed for the investigation of vegetation. The specific spectral design of WAOSS (a red and a near infrared channel) supports the classification of vegetation by means of the NDVI. But in addition to this conventional way the use of the MWIR channel instead of the NIR will be investigated. In this way the atmospheric distortions are minimized. Moreover the WAOSS will be used for cloud investigation too.

Tab.3: Functional top-level mission requirements on the sensor systems

TASK	SPECTRAL REQUIREMENTS	RADIOMETRIC REQUIREMENTS	GEOMETRIC REQUIREMENTS		OTHER REQUIREMENTS
			GROUND PIXEL SIZE	SWATH WIDTH	
hot-spot detection, hot-spot classification observation of volcanoes	3.4-4.2µm 8.5-9.3µm 1 VIS/NIR-channel	temperature estimation within dynamic range >2000, no saturation at T<1300K, rad. resol. within IR >12bit	< 300m	as large as possible, min. >100km	different visir angles at VIS/NIR
determination of VI3 and comparison with the NDVI	840-890nm, 600-670nm, 3.4-4.2µm	≥7bit (VIS/NIR) ≥12bit (MWIR)	100m-300m	small	integer pixel size ratio between VIS/NIR and IR pixels
improvement of Leaf Area Index	840-890nm, 600-670nm,	≥7bit (VIS/NIR)	100m-300m	small	different visir angles
real time detection of clouds, cloud investigation	min. nr. of channels: 3 VIS/NIR +1 TIR	dynamic range >1000	≤ 1km	minimum >100km	stereo capability
test and evaluation of the multi-sensor-multi-resolution technique, test of on-board neuronal network classification	3.4-4.2µm 8.5-9.3µm 1 or more VIS/NIR-channels	≥7bit (VIS/NIR) ≥12bit (IR)	100m-300m	small	integer pixel size ratio between VIS/NIR and IR pixels
technological experiments concerning the infrared sensor system	3.4-4.2µm 8.5-9.3µm	range-level-control, drift- and detectivity control, vibration isolation, pixel alignment	-	-	

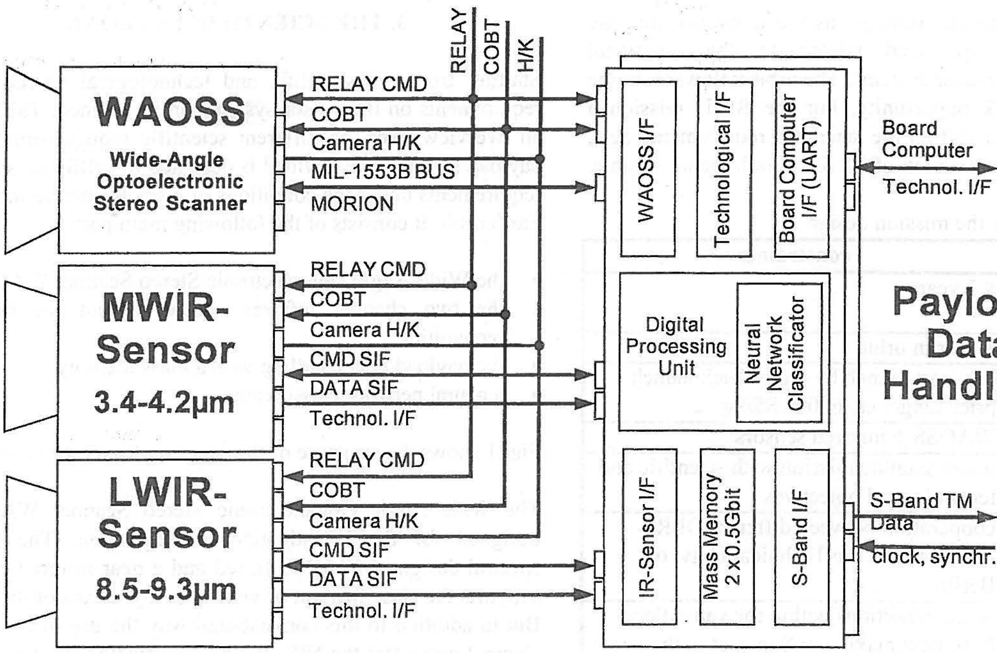

Fig. 1: Scientific payload of BIRD

CMD	Command	MWIR	Medium Wavelength Infrared
COBT	Coded On-Board Time	LWIR	Long Wavelength Infrared
SIF	Serial Interface	I/F	Interface
H/K	Housekeeping Data	TM	Telemetry

The infrared sensor system is designed for hot spot detection and investigation from a small satellite platform. It is described in more detail in (Skrbek et al., 1996). The sensor system consists of two electro-optical detector units for the two infrared channels. Each of them is controlled and cooled separately. But both channels are close connected with their thermal and mechanical interfaces. Some technical and performance characteristics of the sensor systems are summarized in tab.4.

It should be noted that the focal length of the optics is defined in a way that the ground pixel size of the VIS/NIR-sensor (WAOSS) and the two infrared systems are in an integer relationship. The reason is the applicability of the Multi-Sensor Multi-Resolution Technique.

The vegetation sensor and both infrared sensors are controlled completely by the payload data handling system. It consists of a powerful digital processing unit (20 MIPS), a mass memory with a capacity of 2x0.5Gbit and different interface modules to the sensors and to the satellite. It receives the payload commands from the board computer of the spacecraft and transforms these into sensor commands. The sensor signals can be stored on-board, off-line processed on-board or/and transmitted to the S-Band telemetry system. All this is controlled by the payload data handling system.

Moreover the payload data handling system includes a neural network classification experiment. The thematic data reduction on-board should be demonstrated by means of an adaptive classification network. For this purpose an off-line classification process starts after a remote sensing seance. For more information see (Halle, 1996).

Tab.4: BIRD multi-sensor system parameters (altitude 450km)

	WAOSS	MWIR	LWIR
wavelength	(forward) 600-670nm (nadir, bw.) 840-900nm	3.4-4.2μm	8.5-9.3μm
focal length	21.7mm	46.6mm	46.6 mm
Field of View	80°	19°	19°
f# number	4.5	2.0	2.0
pixel size	7μmx7μm	30μmx30μm	30μmx30μm
pixel number	5184	2x512 staggered	2x512 staggered
quantization	11bit	16bit	16bit
ground pixel size	145m	290m	290m
swath width	753km	148km	148km
net data rate	(with compres.)597kbps	420kbps	420kbps

WAOSS - Wide-Angle Optoelectronic Stereo Scanner
MWIR - Medium Wave Infrared Sensor
LWIR - Long Wave Infrared Sensor

4. THE SPACECRAFT

The satellite (fig. 2) consists primarily of

- a spacecraft bus service segment,
- an electronics segment,
- a remote sensing payload segment,
- fixed and deployable appendages.

One main design driver for the spacecraft bus consists in the requirement to be able for a piggyback launch strategy. The total mass should be lower than 100kg, the spacecraft structure shall be compact and the dimensions of one basis side should be in the order of 50cmx50cm. The other main design drivers for the spacecraft bus are the high electrical power requirements from the payload and the high thermal conditioning requirements. Especially the two channel infrared system requires during the duty cycle about 120W because of the use of the two Stirling coolers and the special electronics for control and preprocessing of the infrared detector signals. The total peak power consumption of the satellite during the duty cycle is more then 200W. As already mentioned it requires also a very specific thermal control system.
Some main spacecraft characteristics are given in Tab.5. A more detailed information is given in (Stelter and Walter, 1996).

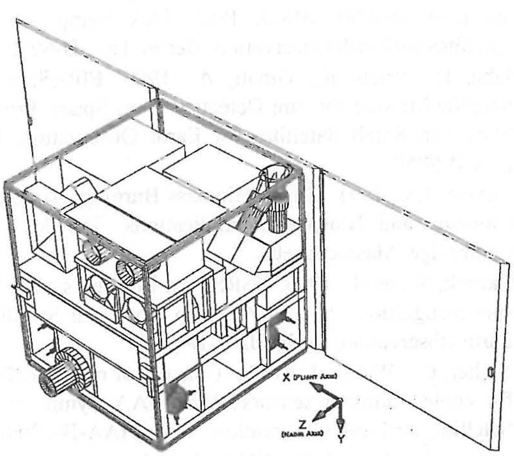

Fig. 2: Spacecraft in flight configuration

Tab. 5: Satellite characteristics

	baseline
Total spacecraft mass	85 kg
Payload mass	26 kg
Power av.	40W
Stabilization method	3-axis stabilized
Pointing accuracy	±5' per axis
Pointing knowledge	±0.2' per axis
Communication	S-Band
Planned launch date	1999/2000
Life span in orbit	1 year

5. THE MISSION ARCHITECTURE

The mission and communication architecture is depicted in fig.3. The mission will be controlled from the German Space Operations Center (GSOC) of DLR in Oberpfaffenhofen. It sends the tele-commands and receives the housekeeping data via its ground station in Weilheim. It should also be a fall-back option for data reception.
The main ground station for receiving and preprocessing of the scientific data is the DLR ground station in Neustrelitz (Germany).

This ground segment will be supplemented by a mini ground station in Berlin-Adlershof for experimental purposes. This ground station should be an example for a low-cost ground station of an local user. It is a simplified S-band ground station consisting of a small antenna and an inexpensive equipment. It has a limited receiving range and it is tailored to the needs of a local data user.

Although the mini ground station should have the possibility of reception of all housekeeping data and of uplink of commands (in an experimental mode) it should not substitute the professional mission control by the GSOC.

The science team organizes the field experiments for validation and for support of interpretation of the remote sensing data by airplane experiments and ground truth measurements.

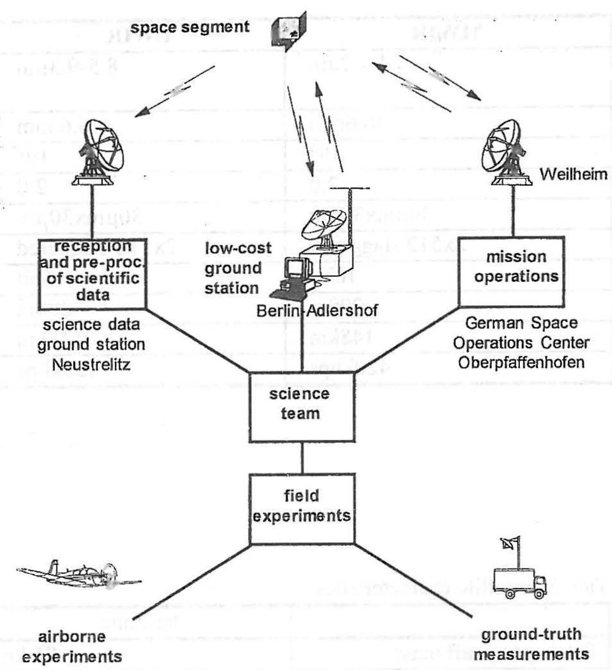

Fig.3: BIRD mission architecture

The data utilization concept is based on the following assumptions:

- The scientific raw data will received, pre-processed and distributed via the data receiving station of the German Remote Sensing Data Center in Neustrelitz. It will store, process on defined levels and distribute the data to the user community.

- Specific on-board classified data will be sent down as a broadcast message in S-band to local user stations within the visibility range of the system. It is an experimental mode, it means still non-operational.

- Fire experiments created from the science team will be supported by ground truth and airborne measurements and carried out in a joint effort with local users.

6. SUMMARY

1. Starting from their FIRES proposal (Jahn et al., 1996) the DLR makes a new approach in the design of a small satellite mission dedicated to hot spot detection and evaluation: the BIRD mission. The new approach is characterized by a strictly design-to-cost philosophy.
2. The BIRD mission tests a new generation of infrared array sensors adapted to Earth remote sensing objectives by means of small satellites.
3. A two-channel infrared sensor system in combination with a Wide-Angle Optoelectronic Stereo Scanner shall be the payload of a small satellite (80 kg) considered for piggyback launch.
4. The main scientific objectives consists in the detection and investigation of hot spots (forest fires, volcanic activities, burning oil wells or coal seams) from space and in the early diagnosis of vegetation condition and changes.
5. To meet these objectives new scientific methods and algorithms will be applied or developed like the Dozier Method, the vegetation classification by means of the MWIR, the Multi-Sensor Multi-Resolution Technique a.s.o.
6. The presented small satellite project BIRD improves the remote sensing component of the fire-ecological research in a global scale.
7. The thematic on-board data processing will be demonstrated by means of a neuronal network classificator in orbit.
8. The BIRD concept opens a future direction by:
   - the implementation of new infrared sensor technology in space,
   - the on-board correction of the sensor signals,
   - on-board thematic data reduction and generation of high-level data products,
   - direct transmission of data products from the satellite to a local final user without relevant delay.

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