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Flight Tests and Demonstration with a BK117 Equipped as an Environmental Helicopter

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1 Introduction

In the summer of 1998, a customer (Hungary) contacted Eurocopter because he was interested in an Environmental Helicopter (EHC) System developed by Eurocopter Deutschland (ECD). The customer became aware of this concept due to previous publications by ECD concerning the EHC. To get an EU financing from Brussels the customer needs to prove the ability of the Airborne Environmental Monitoring and Control System (meaning a helicopter as a platform for special sensors) in a demonstration campaign. Therefore a BK 117 helicopter was equipped with a thermal imaging and measuring camera (AGEMA) and a high resolution line scanner (WAAC). A first measurement campaign was performed in South Bavaria in December 1998. There were additional measurement flights and presentations in Hungary in June 2000.
This paper descibes the sensors, the setup in the helicoper, the flight trials and the results of these flight trials.

2 Environmental Helicopter Concept

The EHC concept is characterised particularly by its modularity. It allows optionally using different sensors on one helicopter with the necessary basic equipment, depending on the requirements, i.e. versatility. [/1/, /3/, /5/]

The basic equipment comprises an operator's workplace, a data recording device and a measuring installation for the specific situation (helicopter position and attitude, time, air temperature, etc.). The operator's workplace features a display and control units for the sensors, data recording and data processing.

The environmental helicopter's modular system not only permits of fast modification of various sensor. Thanks to its multifaceted equipment, the EHC is capable of carrying out a whole host of tasks. These tasks cover observation, mapping, measurement, monitoring, taking an inventory, predictions of a greater resolution than ever been achieved before.

The following list gives some concrete examples of such assignments divided into topic areas:

- Environmental condition:
  Topographical photographs, emissions, immissions, depots
- Water quality:
  Groundwater, floods, degree of contamination
- Agriculture:
  Forest damage, soil conditions (dry, damp), land use, harvest forecasts, vitality of vegetation
- Infrastructures:
  Gas, oil, telephone and power supply lines, drainage, condition of canals, road and rail networks, airfields
- Communal monitoring:
  Development condition, green areas, space situation, hills
- Fire Detection:
  Forest fires
  Landscape fires

The environmental helicopter can be used to a particular advantage when sensors are only to be moved slowly or need to perform stationary measurements. Such sensors are, for instance, the Gas Chromatograph Mass Spectrometer (GCMS) for the chemiphysical analysis of the atmosphere as well as LIDAR systems.

A complete EHC concept must cover, in addition to data recovery, data processing up to the preparation of thematical maps. To this end, a suitable data format must already be selected on the helicopter to store the data in a Geographical Information System (GIS System). This GIS software assigns the measured data directly during storage to the appropriate geographical location and also sets time marks. The operator's task is to control and monitor this system in the helicopter. packages but also conversion for other tasks such as transportation, rescue, passenger transport, etc.

2.1 Demonstration Campaign in Hungary

In order to obtain an EU budget the customer in Hungary needs to verify the functionality of an airborne environmental monitoring and control system. A demonstration with at least one of the sensors (IR-camera or line scanner etc.) should prove the ability of such a system.

Therefore a demonstration was planned in Hungary with an ECD helicopter as airborne platform. With a thermal imaging and measuring camera and a high resolution line scanner an approx. 5 km² wide area in Hungary should be monitored. A reference ground monitoring at the same time should help to scale the airborne measurements.

For the campaign a military landing field providing a hangar and refueling facilities was prepared near Györ. It was planned to be five days at this location to find at least two days with adequate weather conditions for remote sensing. The transfer from Germany to Hungary was planned via Austria with refueling and customs in Vienna.

The customer in Hungary organized the following:

- Landing and fly-over license in Hungary
- Fly-over license for Austria (done by ECD)
- Landing site and hangar
- Refueling facilities
- Customs

Due to adverse bad weather conditions the adventury in Hungary had to be canceled in agreement between the customer and ECD.

It was then decided to perform alternatively measurement flights in South Germany in the remaining time slot. There too, only one day provided sufficient weather conditions for remote sensing to show the functioning of the whole airborne measurement system.

First of all, test flights with individual systems were flown from Ottobrunn. The infrared camera together with the WAAC camera including mounting were tested. At last the measurements with all sensors were recorded.

Later in June 2000 a second set of measurements was recorded including two measurement flights in Hungary.

The test flights were done at six days:

- 24.11.98 OTN-Maxlrain-Glonn-Aying
- 25.11.98 OTN-Schliersee-Tegernsee-BadTölz
- 27.11.98 Short flight to Deisenhofen
- 08.12.98 OTN-Ingolstadt-Altmühltal-Manching
- 15.06.00 Ungarn: Plattensee-Veszprem
- 16.06.00 Ungarn: Budapest-Donau-Kecel

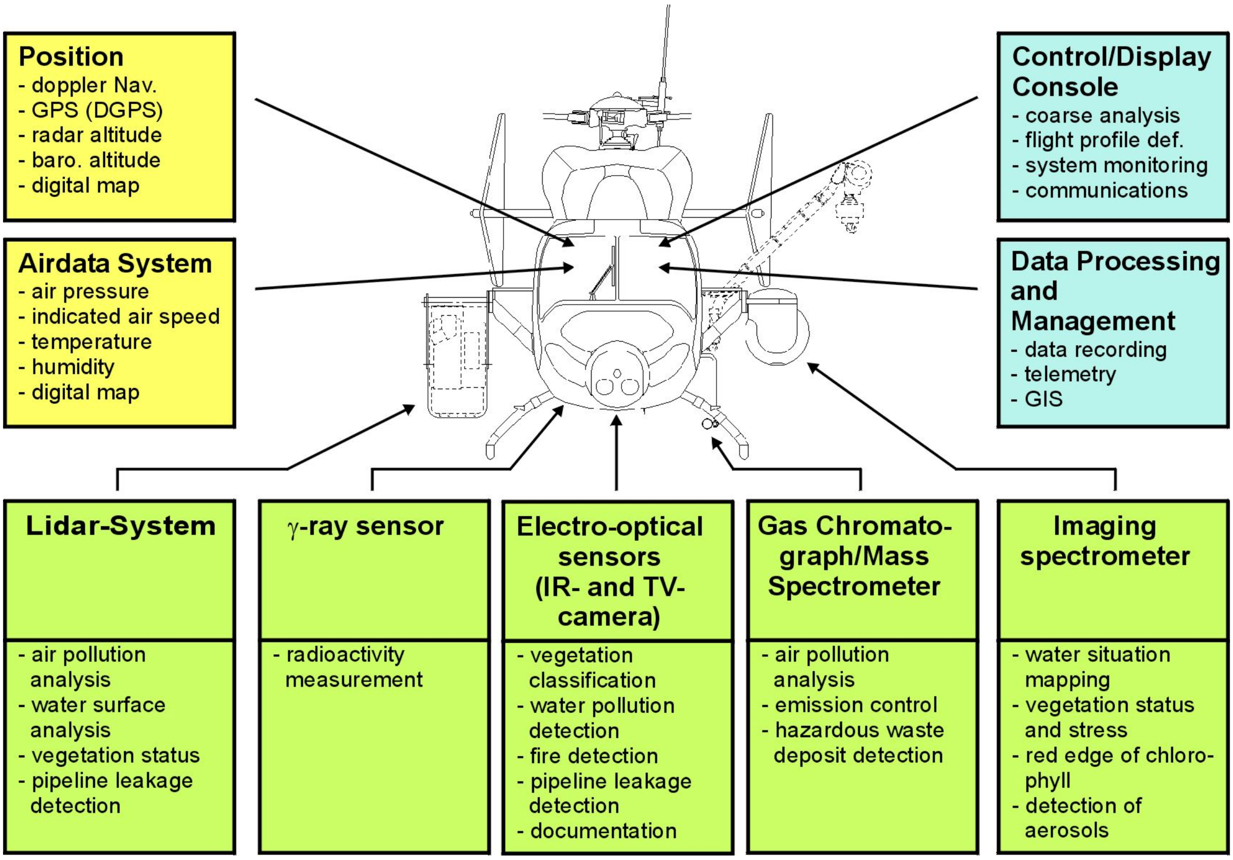

Fig. 1: Modular sensor packages for the Environmental Helicopter (EHC).

3 Measuring Equipment in the Helicopter

The measuring equipment comprised primarily the following:

- 1 stereoscopic camera with 3 channels (type designation 'WAAC [Wide Angle Airborne Camera]')
  (furnished by DLR);
- 1 IR camera type AGEMA THV900 (8-12µm)
  (Eurocopter Deutschland);
- 1 CCD video camera
  (Eurocopter Deutschland);
- 1 digital map unit EuroNav III with GPS
  (furnished by EuroAvionics);
- monitors, keyboards, computer, recorder, etc.

3.1 System Architecture

The individual subsystems (marked grey in Fig. 2) were systems that worked independently during the measurerment flights and could be operated separately. Only in two cases were they interconnected.

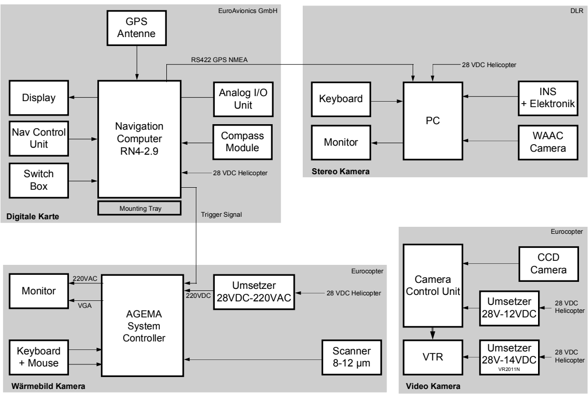

Fig. 2: A block diagram of the test set-up in the helicopter.

4 DLR Wide Angle Airborne Camera (WAAC)

The Wide Angle Airborne Camera (WAAC) is based on a development for a space camera. The WAOSS (Wide Angle Optoelectronic Stereo Scanner) was developed to explore the planet Mars at the Institute for Space Sensors of the DLR (German Aerospace Centre). This led, as the result of further research work, to an electronic, digital air camera for use in aircraft, the WAAC (Wide Angle Airborne Camera).

4.1 Manner of Functioning of the WAAC

The camera works on the scanner principle. The area recorded is imaged on the sensor elements via an optical system. Instead of a film, several CCD lines record the impinging light and consequently scan the area overflown strip by strip. The CCD lines used are sensitive to the colour spectrum from the visible range up to the near infrared. The three-line arrangement makes it possible to obtain video data from three different look angles. These video data can be processed with the aid of a computer to form high-resolution stereo images. Stereo images using all three CCD lines can be implemented starting at a flight altitude of 1,500 metres and above. Below a flight altitude of 1,500 metres, the WAAC serves to take high-resolution air photographs with a high dynamic range of 2,048 shades of grey

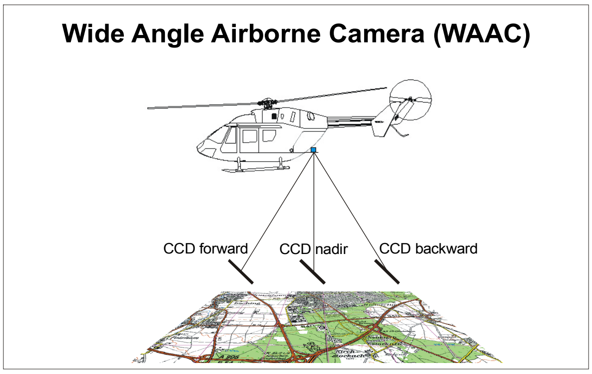

Fig. 3: The functional principle of the 3-line CCD camera. With the three look angles, a three-dimensional image can be calculated in the computer.

The stereo video data permit preparing digital terrain models (DTM), a three-dimensional presentation of the topography. The sensitivity of the CCD lines of the WAAC permits, when using suitable filters, the image-related coverage of, for example, environment-relevant conditions of the vegetation (forest, agriculture, waters, etc.). WAAC can justly be described as the forerunner of a new generation of cartographic cameras.

Here are some possible applications of the WAAC:

- air photogrammetry (land registry office);
- environmental monitoring;
- data classification for town and landscape planning;
- topography.

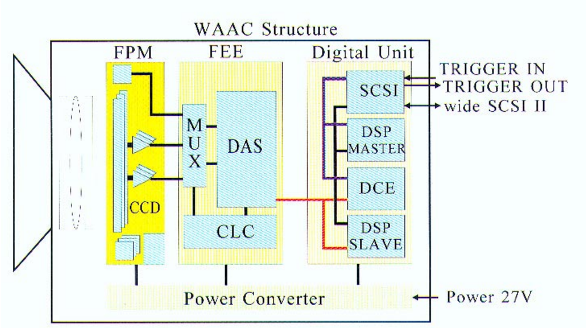

Fig. 4: A block diagram of the WAAC electronics.

4.2 Technical Data of the WAAC

Parameter	WAAC Scanner
Optics and Metrology	
FOV	80°
Focal length	21.7 mm
No. of CCD arrays	3
Distance between CCD arrays	10.1 mm
Angle of convergence	25°
IFOV (square)	3.23 x 10-4 rad
Detector elements per CCD array	5,184
Distance betw. detector elements	7 µm
Swath at a flight altitude of 3 km and v = 200 km/h (nadir CCD)	5.184 km
Minimum position resolution at a flight altitude of 3 km and v = 200 km/h	
in flight direction	0.97 m
laterally to the flight direction	0.97 m
Radiometric resolution	8 bits
Radiometric dynamic range	11 bits (2,048 shades of grey)
Spectral sensitivity	
nadir	580...770 nm
forwards, backwards	470...670 nm
Size	285 mm x 190 mm x 202 mm
Power requirement	15 W
Scanner weight	4.4 kg

5 AGEMA IR camera

5.1 Technical Data of the 8-12 µm Scanner

The IR measuring system supplied by the AGEMA company comprises two IR cameras (so-called scanners) which feature differing detectors and therefore have different spectral sensitivity ranges. The 8-12 µm detector is used for environmental analyses, as it is particularly sensitive in the ambient temperature range.

The IR cameras are operated via a system controller which, among other things, controls their operation and effects signal processing and conditioning of the sensor signals. The measuring system also includes a customary PC keyboard and pointing device (mouse) (for block diagram see Fig. 6)

Fig. 5: Sensorhead, processor and special keyboard of the AGEMA-camera.

The technical data of the two IR cameras are given in the following table.

Parameter	LW Scanner
Scanner	
Detector	HgCdTe
Spectral sensitivity range	4 µm - 13 µm (without filter)
Filter	LPL Long pass $\lambda_{cut\ off}$= 7.4 µm
Image frequency (1/s)	15
Lines/image	136
Pixels/line	230
Geometric resolution (MTF 0.5)	0.76 mrad (field of view 10°)
Scans/line	272
Thermal resolution (NETD at 30°C)	0.08°C
Detector-cooling method	Stirling
Optics and Metrology	
Field of view (FOV) (hor x vert)	10° x 5°
Temperature measuring ranges (with LPL and SRX filter)	I) 0°C to 500°C II) 50°C to 350°C III) 150°C to 1,000°C IV) 250°C to 2,000°C
Dynamics	12 bits (4,096 stages)
Data output	digital
Accuracy	+/-1°C (resp. +/- 1% of the measuring range
Scanner weight	3.5 kg

The appropriate curves have been provided by the manufacturer for the spectral sensitivity ranges. By connecting IR filters (LPL and SRX) ahead, the spectral sensitivity can be narrowed down to the desired spectral ranges within the primarily specified sensitivity ranges.

5.2 Description of the AGEMA Software

The temperature data recorded by the scanners are digitised with a data depth of 12 bits (4,096 shades of grey) and stored as individual images on a 100 MB hard disk as raw data. During recording, merely the temperature range (I-IV) need be set. The object parameters emissivity [ε], ambient temperature on the measured object [°C], air temperature [°C] and object distance [m] can still be set after measurement during

image evaluation. The equipment software computes the indicated temperature values from the object parameters. Dynamic processes can be stored with up to 30 shots per second. It is also possible to record a screen dump on a video recorder.
The raw data stored can be displayed in various colour and black-and-white presentations. The following colour displays can be selected: rainbow, tempering colours of iron, 16 colours, 10 colours and 5 colours as well as all presentations inverted. With black-and-white presentations there are: grey wedge, 16 shades of grey, 10 shades of grey and 5 shades of grey as well as all presentations inverted. The colour bar on the right in the figure (see thermal pictures Chapter 9) shows the assignment between temperature values and colours. The range of the temperatures shown in the figure can be set freely as regards its position on the temperature scale (level), as well as in its span. If temperatures occur in the image that lie above or below the set colour bar, these are displayed in white or black, respectively (illustrated by the example of the most used colour scale, namely rainbow). If image ranges lie at temperatures beyond the calibrated temperature range set prior to measurement (I-IV), these are marked in a special red tone. A narrow horizontal bar below the thermal picture indicates, in relation to the set colour bar, which temperatures occur in the image. The file name, date and time of recording as well as a remark (8-12 µm or 3-5 µm channel) are given in the light blue area below the image.

The software supplied by AGEMA offers diverse image-processing tools for analysing the thermal pictures. The temperature at any points can be determined by means of so-called spot meters. The temperature profile can be indicated along a line. Further, there are some statistical functions such as the mean temperature value of an area (circle, box, etc.).

In order to be able to print the analysed images, the software offers export drivers for .TIF, .GIF and .PCX, whereby the images are stored on the integrated 3 1/2" drive in DOS format. Further, the AGEMA system can be connected via an Ethernet interface directly to the ECD network. Measurements can also be stored directly on an external hard disk.

5.3 The Measuring Set-up in the Helicopter

The measuring system comprises the following equipment:

- AGEMA System Controller;
- AGEMA Keyboard;
- AGEMA Scanner 8-12 µm;
- Mouse;
- VGA/Video Monitor;
- Converter 220V to 28V.

The command to store an image is triggered on the keyboard. Triggering by the digital map unit supplied by EuroAvionics was also envisaged for the flight tests. However, this functioned only on the ground in the demonstration mode. The scanner focus can also be remote-controlled from the keyboard.

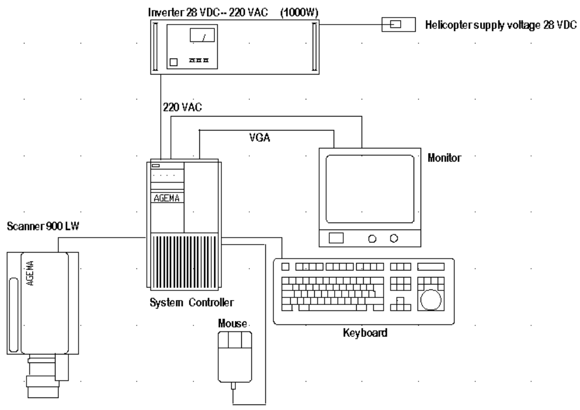

Fig. 6: Measuring-system components of the AGEMA camera

6 CCD Camera

The CCD camera is a 1-chip CCD camera with a remote camera head. The control unit was mounted on the AGEMA rack. The camera emits FBAS and S-VHS video signals. The S-VHS images were recorded on a video recorder, which was likewise installed in the AGEMA rack. The CCD camera was used to take reference pictures.

Fig. 7: Camera head (in front) and control unit.

7 Digital Map Unit supplied by Euro Avionics

The EuroAvionics company provided a digital map unit free of charge for the EHC demonstration campaign. This EuroNav III is based on an integrated GPS sensor module. It has been designed mainly for use in helicopters as a navigation and flight planning system. Besides detailed map displays, the system provides additional functions which are helpful for police, rescue or observation missions. Further functions can be programmed according to the customer's wishes.

In addition to the internal functions, the EuroNav III also features diverse interfaces which permit of data exchange with and control of other equipment. For instance, the position of a FLIR camera can also be recorded in-flight. The observation cone on the Earth's surface can be computed with the map and height information.

With respect to the assignments to be performed by an environmental helicopter, the remote sensing cameras can be triggered, for example, in addition to flight planning and recording.

7.1 Setup of the EuroNav III

The EuroNav III comprises a central computer in an ARINC housing. It contains its own GPS. Two slots permit inserting hard disks on which the operating system and the desired map basis are loaded. Further, the digital map system features the following components (see Fig. 8):

- TFT-Farbdisplay 10,4“ (2)
- Navigation Control Unit (4)
- Switchbox (6)
- Compass Module (12)
- Analog I/O-Unit (13)
- Mini-Keyboard (5)
- GPS Antenne (8)
- Kabelbaum (A, B...)

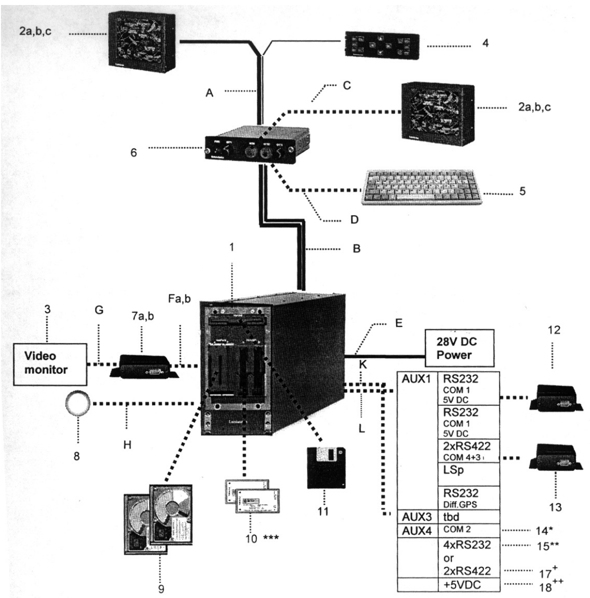

Fig. 8: Block diagram of the DKG supplied by Euro Avionics.

The compass module contains a magnet field sensor to support the heading information, if the latter is not provided by a heading gyro.

The EuroNav III permits storing the stored flight immediately after landing on a 3 ½" diskette. The appropriate drive has been installed for this purpose. The data can also be processed later on the PC (S/W undergoing preparation at EuroAvionics). Likewise, the entire flight planning can be performed on the PC and then transmitted via diskette to the helicopter.

7.2 Maps and Database

The EuroAvionics map system can present a digital map (vector map), an ICAO vector map, or optionally own scanned maps (grid maps). The vector maps are based on an intelligent database which also contains place names, road names, etc. The system includes the Jeppesen database as well. Pressing a button permits changing between various map scales. Software can be used to set the desired map (vector, grid or ICAO map) with the required scale.

Up to 3,000 waypoints can be read in and stored for flight-path planning.

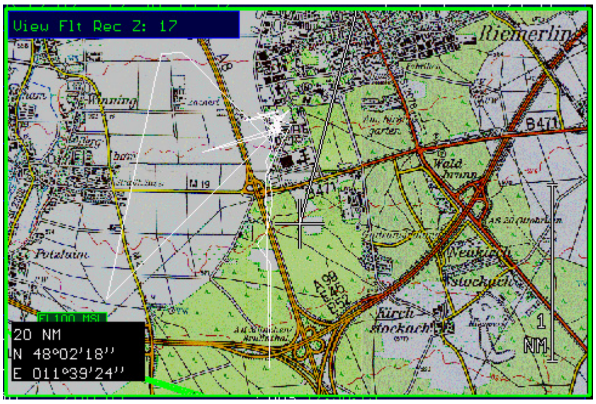

Fig. 9: Scanned-in raster map of Ottobrunn and the surroundings.

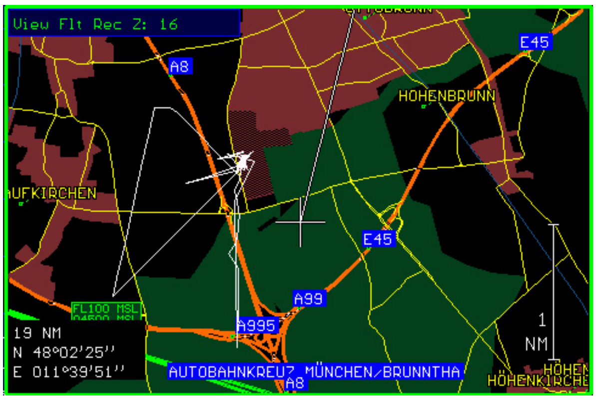

Fig. 10: Vector map out of the EuroAvionics data base including object overlay.

8 Results with the WAAC camera

The data of the flights with the WAAC were stored on the hard disk of the WAAC PC and processed upon completion of the flight. Eliminating the helicopter movements and vibrations during processing was performed at the DLR Institute in Berlin. It was found that the vibrations as well as the roll, yaw and pitch movements of the helicopter were too large for the camera system, and could not be eliminated entirely. The customer solution foresees a better installation e.g. in the helicopter's nose or on a stabilized platform.

During the flight test, the length of the desired sequence as well as the current flight altitude above ground had to be read into the WAAC PC in order to trigger video recording.

Fig. 11: WAAC film strip above Bad Tölz. Compare with fig. 12

The effect of the position of the sun and the atmospheric attenuation should not be neglected when using the WAAC. The optimum is an almost perpendicular sun (little cast shadow) and a clear day without cloudiness (no attenuation, no cloud shadows). These prerequisites were not the case during the two test flights. For instance some images show strong bright-dark differences. Shadows of forest edges and clouds can also be seen. The sun was already very low (winter afternoon).

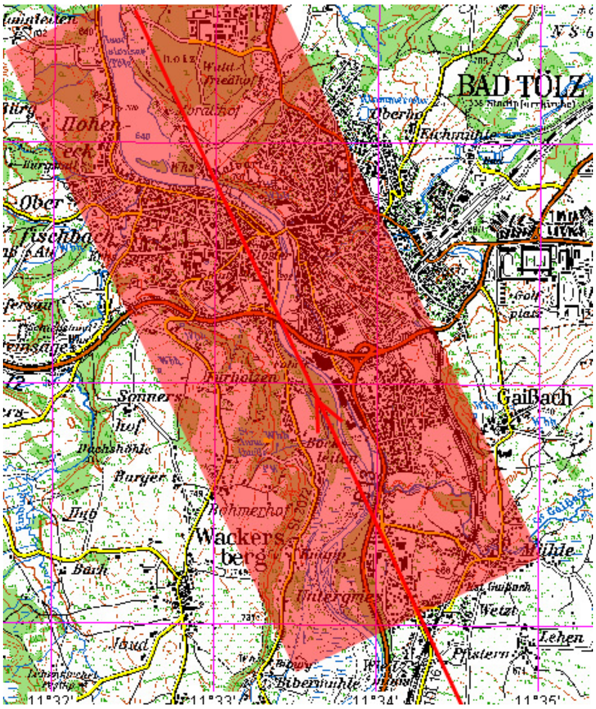

Fig. 12: Topograpy Map above Isar near Bad Tölz. The grey (red) marked area highlights the sensor scanning field of view, see also fig. 11

9 Results with the der AGEMA-camera

The AGEMA camera internally produces an ongoing data stream which can be presented as a video or VGA signal. However, storage is effected in individual frames. In order to be able to record strip-by-strip images, overlapping individual images must be stored. It is be possible to externally trigger the overlap of 10 – 30%. The AGEMA system offers an interface for this.

The individual images are then brought in a PC programme supplied by AGEMA to the same temperature setting and stored as .BMP. The individual images must be made to overlap manually in an image-processing programme and joined to form an image-strip. Two examples of image-strips generated in this way are presented in this paper. The first image-strip was recorded on the flight above Ingolstadt on 08.12.1998. The second image-strip was created on the same day during the return flight above a refinery to the east of Ingolstadt.

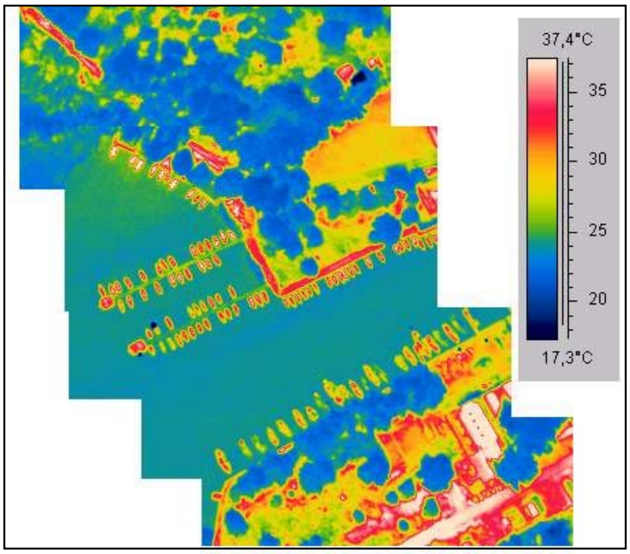

Fig. 13: Marina at lake Balaton close to Veszprem in Hungary

Photo of a oil refinery

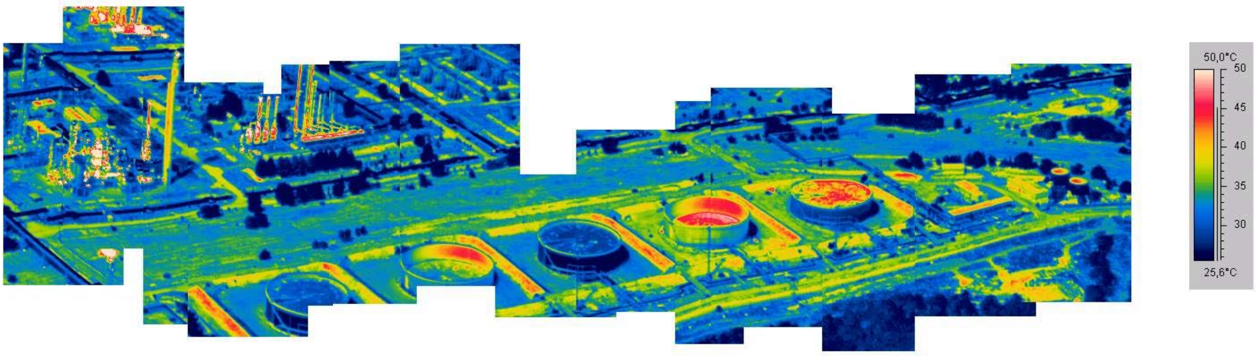

Fig. 14: Oil refinery in Hungary. The oil level in each tank can be seen with the infrared camera.

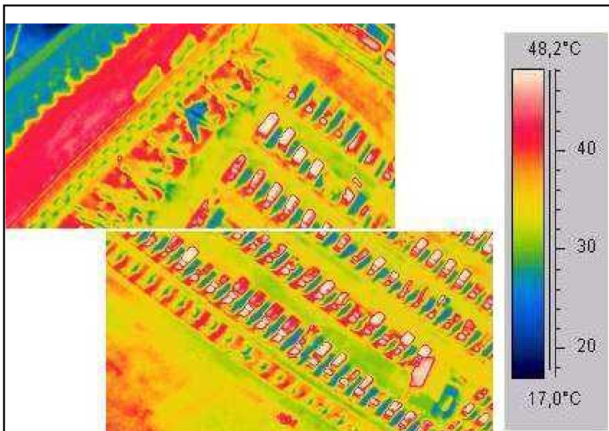

Photo of the collection in Kecel

Fig. 15: Privat collection of military vehicles and military airplanes in Kecel, Hungary

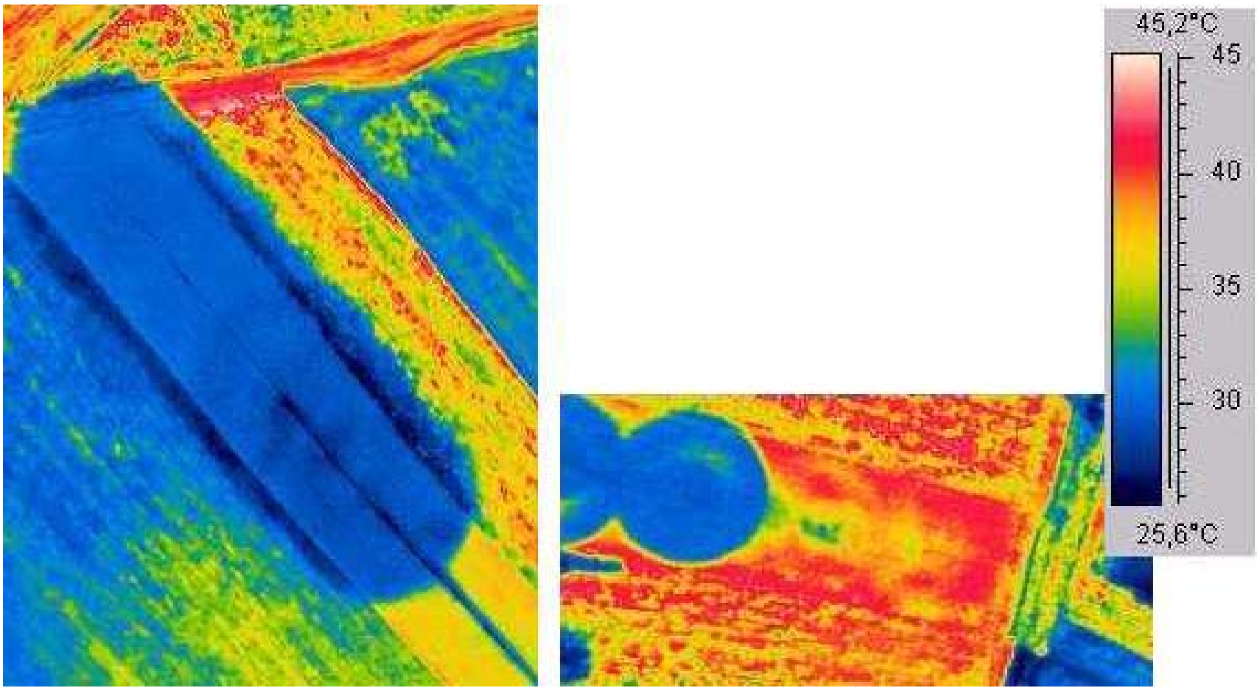

Fig. 16: Irrigation of fields in Hungary. The dark (blue) areas are showing cooler surface temperatures because of circular irrigation.

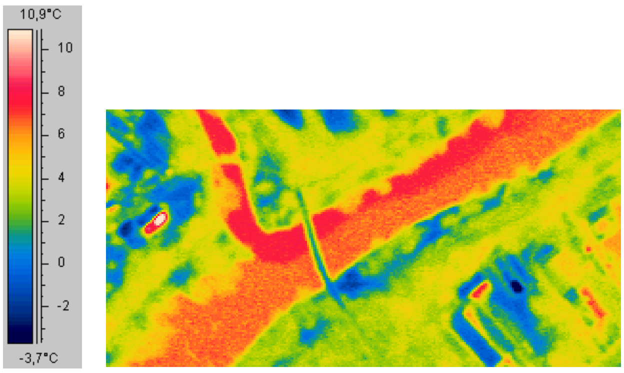

Fig. 17: Influx of a stream about 7.8° cold into the Mangfall river 6.5° cold.

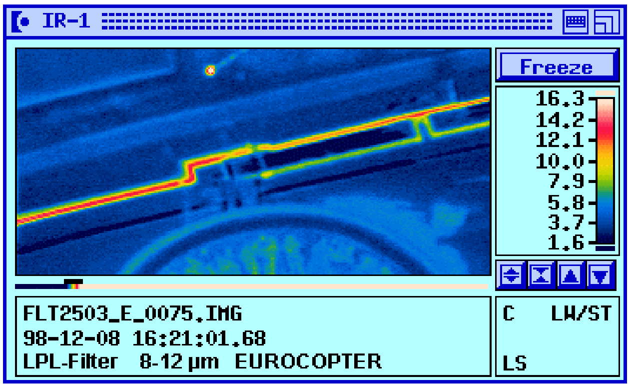

Fig. 18: Pipeline in a refinery. The medium transported is warm. The pipeline is obviously leakproof.

10 Summary

10.1 The Potential Offered by the Environmental Helicopter

The flight trials carried out as part of this demonstration campaign proved to be very useful in showing the potential offered by a BK 117 equipped as an environmental helicopter.

A UHS can perform the following tasks:
- Monitoring;
- Mapping;
- Inventoring;
- Forecasting;
- Controlling.

Thanks to the extensive observations carried out in recent years as well, ECD now has at its disposal the appropriate know-how for putting together and developing an optimal EHC package for every customer wish. Due to its size and permissible take-off weight, the BK 117 has proved to be a particularly suitable platform. The EHC package can also be installed as a retrofit kit in rotorcraft that have already been sold.
The modular system of the environmental helicopter not only permits of fast retrofitting of various sensor packages but also of retrofitting for other assignments, for instance transportation, rescue, passenger transport, etc.

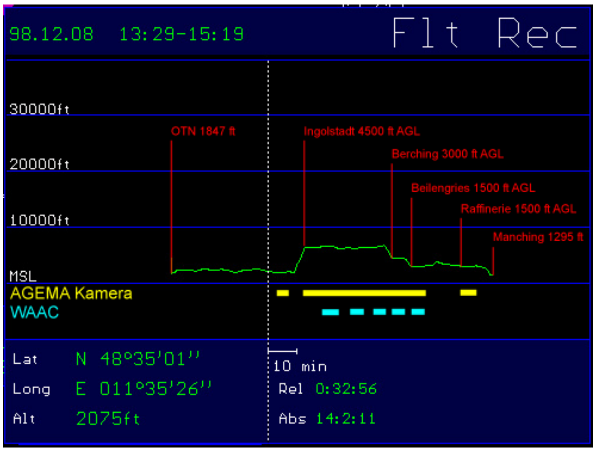

Fig. 19: Flight profile of Flight 2503 on 08.12.98. Also included are some places and the recording times of the AGEMA camera and the WAAC.

10.2 Results and Outlook

Even if no sensor calibration was performed through ground measurements, the sensors did in fact yield meaningful results. Using the IR camera, longer film strips could be recorded and joined together for the first time. Industrial plants together with agricultural, forest and urban areas were observed. The IR film strips generated in this way are suitable for studying urban climate, pipeline monitoring, power supply line monitoring, revealing environmental pollution (inlet of industrial wastewater), etc. However, vegetation measurements should be conducted in spring, summer or early autumn.

The WAAC camera is a suitable device for taking high-resolution pictures for topographical purposes right up to the preparation of three-dimensional landscape models. Both cameras should be operated in stabilised and damped platforms in order to compensate for the helicopter's movements and vibrations, respectively. A TV camera in the same direction of view as the IR camera is highly to be recommended for documentation purposes.

A digital map unit such as the EuroNav is required for mission planning, implementation and post-processing. It should feature a DGPS receiver in order to comply with the stringent requirements placed on position determination. The pilot needs a display of the flight path to be flown and the necessary flight altitude.

In order to be in a position to offer the environmental helicopter on a technically and scientifically sound basis, the post-processing of the sensor data and the image processing must also be considered. A lot of additional experience was obtained in this area, too, during this demonstration campaign.

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