A Laser Fluorosensor for Airborne Measured of Maritime Pollution and of Hydrographic Parameters

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ABSTRACT

Since 1986 two Dornier DO 28 D2 surveillance aircraft have been flown in the German responsibility areas of the North Sea and the Baltic Sea. In 1991 a new DO 228-212 aircraft has been put into operation with improved performance. A laser fluorosensor will be integrated in 1992 as a new component of the sensor package. The paper describes some specifications of this instrument.

INTRODUCTION

In 1985 two Dornier DO 28 D2 aircraft were procured by the Bundesministerium für Verkehr and by the federal coastal states of Bremen, Hamburg, Niedersachsen and Schleswig-Holstein for maritime surveillance in the Federal Republic of Germany. They were brought into service at the beginning of 1986 (Schroh and Bustorff, 1989). The aircraft are equipped with side-looking airborne radar (SLAR) for detecting slicks over long distances, a UV/IR line scanner for mapping the distribution of oil film thickness, and an operator console for displaying TV images, SLAR and UV/IR scanner data on two TV monitors.

The Bundesministerium für Verkehr decided to realize a second generation maritime surveillance system in 1988. In addition to the sensors utilized up to this time in the first generation aircraft, the new system will include a microwave radiometer (MWR) and a laser fluorosensor (LFS) to meet the requirements of a more quantitative analysis of pollutants (Grüner et al., 1991).

These two instruments are under development at DLR Oberpfaffenhofen and at the University of Oldenburg, respectively,in cooperation with Krupp MaK Maschinenbau, Kiel. The sensors work under control of a new Central Operator Console (ZOP) which has been developed by Krupp MaK. A Dornier DO 228-212 aircraft has been selected as the carrier with modifications of the avionics (OMEGA and GPS navigation, data down link to oil combating ships), and of the fuselage for allowing an integration of remote sensing instruments.

This paper describes the optical layout of the LFS, according to the state of the prototype development in early 1991. The method of interpreting the data obtained from slicks on the sea surface is described in a separate paper (Hengstermann and Reuter, 1991) in this issue.

1. DESIGN AND SPECIFICATION

1.1 Operation tasks

Application of the laser fluorosensor for maritime surveillance shall allow to evaluate the following information:

* identification of substances on the sea surface (toxic/harmless/natural), and classification of pollutants (e.g. heavy/medium/light fuel oil)
* calculation of the film thickness of oil spills in the range of about 0.1 to 10 µm, and estimation of the oil volume from a two-dimensional mapping of spills,
* detection of swimming chemicals and of substances drifting underneath the sea surface.

In addition to this, other applications in the field of oceanography are intended, like

* the measurement of gelbstoff for describing hydrographic conditions in coastal waters, and
* the measurement of algae for estimating the biological productivity.

The laser fluorosensor has been designed to meet the requirements of these different tasks. The most important operational specifications of the instrument are listed in Table 1. A scheme of the optical setup is displayed in Fig. 1. Layout and functional characteristic are based on the experience obtained with the Oceanographic Lidar System (OLS), a time-resolving lidar developed for oceanographic applications. OLS was utilized in the period 1983-86 as an experimental sensor in various airborne experiments (Diebel-Langohr et al. ,1986a,b), which included also measurements over oil spills (Hengstermann and Reuter, 1990).

Table 1: Operating properties

size (l x w x h)	1270 x 355 x 978 mm excimer laser	
	961 x 460 x 944 mm detector unit	
weight	300 kg	
flight height	1000 ft typ.	by daylight
	3000 ft typ.	at night
aircraft ground speed	100-200 knots	
electrical power	1.0 kVA	in standby
	3.4 kVA	at 110 Hz pulse rate
data interpretation	real time	
distance of eye-safe operation	>50 m	

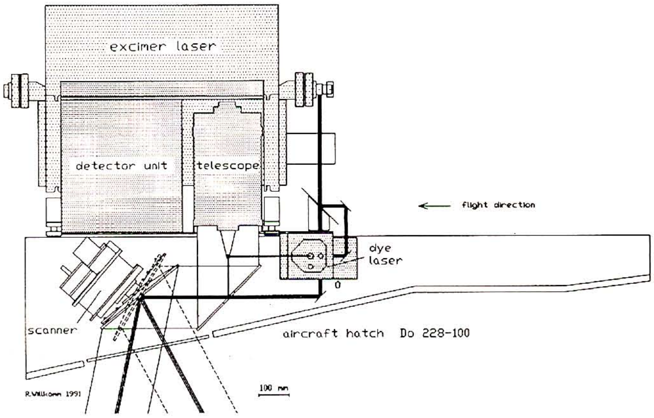

Fig. 1 - Scheme of the laser fluorosensor. Position of the scanner is above a bottom hatch of the aircraft which is sealed by a quartz window for protection of the optical components. The detector unit contains the 12 channel spectrograph, the gated integrator, and the computers for sensor control and substance classification.

1.2 Lasers

A XeCl excimer laser, and an excimer laser pumped dye laser are the light sources of the laser fluorosensor (Table 2). Both lasers are based on standard products of Lambda Physik, Germany.

The excimer laser is a modified version of the Lambda Physik model LPX 110. A pulse energy of 150 mJ allows to measure fluorescence from the sea surface also under full daylight conditions. With operation of the scanner, the 200 Hz peak repetition rate is high enough to obtain a two-dimensional mapping in the nadir range of the flight track.

Table 2: Lasers

	XeCl excimer	dye
emission wavelength	308 nm	382 nm
pulse energy	150 mJ	20 mJ
pulse length	20 ns	15 ns
beam divergence	5 mrad	3 mrad
repetition rate	200 Hz max.	20 Hz max.
	110 Hz av.	5 Hz typ.

The laser head was entirely disassembled and modified in order to reduce its relatively high weight, and to change the orientation of the originally flat mounting into an upright position (Fig. 1). Electronic compounds of the laser head were replaced by DC versions for operation with the 28 V power lines of the aircraft; this includes also the laser power supply, which has been integrated into the case of the laser head for improving the electrical safety. To meet the regulations of EMI emission for avionics instruments, the case of the laser head has been designed taking particular care to its EMI shielding characteristic.

The 308 nm excimer laser wavelength is useful for an excitation of fluorescence signals which originate from slicks on the sea surface, or from dissolved organic matter in the water column like Gelbstoff (Hengstermann and Reuter, 1990). If the thickness of oil films is calculated from the depression of water Raman scattering, shorter laser wavelengths - and hence higher absorption coefficients of oil - would allow the analysis even thinner films. However, attenuation losses in the atmosphere become more dominant in the spectral range below 300 nm, and this degrades the measurement of water Raman scattering. The dye laser, a modified Lambda Physik model FL 105, is mainly used for exciting the fluorescence of chlorophyll in algae. Its emission wavelength is set to 382 nm by use of the laser dye polyphenyl 2 dissolved in water; this is, for reasons of security in the aircraft, preferable when compared with solutions of dyes in alcohol. An emission wavelength below 400 nm is mandatory as well to meet the regulations of an eye safe operation for typical flight heights of 300 m.

An excitation in the blue absorption band of chlorophyll, where laser dyes with better efficiency and stability than polyphenyl 2 are available, would increase the intensity of chlorophyll fluorescence signals by about one order of magnitude. However, chlorophyll detection with the 382 nm dye laser wavelength is still advantageous when compared with the 308 nm excimer wavelength, if the optical properties of other substances in the water column are taken into consideration. In particular, the absorption characteristic of gelbstoff is exponentially growing from visible to UV wavelengths. Therefore, laser pulse penetration into the water column is higher at 382 nm, and this allows also the detection of subsurface maxima of phytoplankton.

1.3 Telescope and scanner

A f/10 Schmidt-Cassegrain reflective telescope with an entrance aperture of 20 cm is used. To increase the efficiency in the UV, the Schmidt correction plate is replaced by a quartz window.

Particular emphasis has been focused on the capability of two- dimensional mapping of the sea surface. This is done by use of an optical scanner, manufactured by Optech Inc. Toronto, according to the following specifications:

- a swath width of 150 m is obtained from 1000 ft aircraft flight height;
- the scan pattern on the ground is uniform and, typically, the pixel distance shall be 10 m, with 120 kn aircraft ground speed and 200 Hz peak laser repetition rate.

Fig. 2 shows the pixel distribution defined for oil spill mapping by using the excimer laser at its peak repetition rate of 200 Hz. With this scan pattern, the average laser repetition rate is 110 Hz. A sequential operation of both lasers, excimer and dye, is carried out by use of a rotating mirror used for pumping of the dye laser synchronously to a predefined angular position of the scanner mirror.

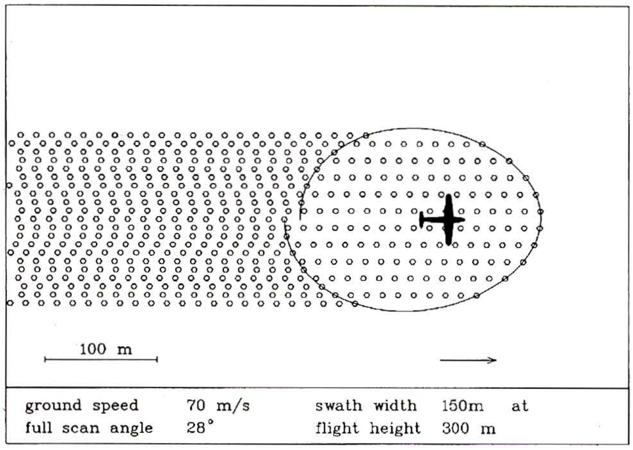

Fig. 2 - LFS pixel distribution on the sea surface for oil spill mapping with 200 Hz peak repetition rate of the excimer laser. Laser pulse triggering is controlled by the angle encoder of the scanner, to obtain a mostly uniform pixel coverage of the sea surface.

This mode of operation will be used for hydrographic mapping of small-scale structures on the ground, like tidal flats of the Wadden Sea; Fig. 3 displays an example of the pixel distribution.

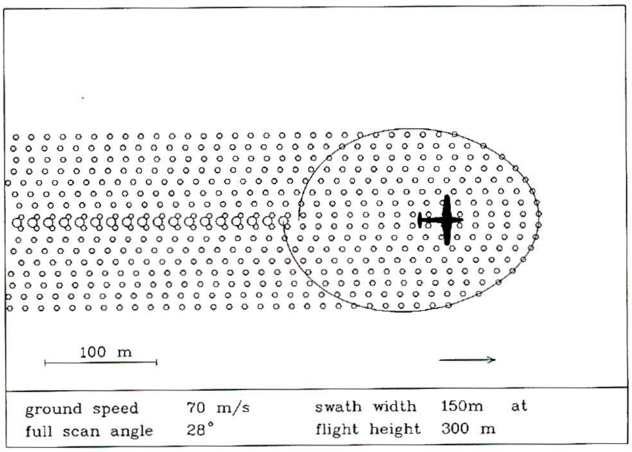

Fig. 3 - LFS pixel distribution on the sea surface for hydrographic mapping with parallel operation of the excimer laser (small circles) and dye laser (large circle).

Table 3: Telescope and scanner

Receiver telescope:	reflective, Schmidt-Cassegrain
entrance aperture	20 cm
f-number	f/10
Scanner:	conical type
full scan angle	28° across-flight, 35° in-flight
scan frequency	≤20 Hz, selectable
swath width	150 m @ 1000 ft. flight height
pixel-to-pixel dist.	10 m typ. @ 1000 ft flight height, 200 Hz max. laser rep. rate

The 13 inch scan mirror is made of aluminum with protective coating. Its central part consists of a 2 inch dichroic laser mirror, with a damage threshold sufficiently high for reflecting the 308 and 382 nm laser beams. The two mirrors are parallel within 0.5 milliradians.

The position of telescope and scanner above the aircraft bottom hatch, and the path of laser beams, are shown in Fig. 1. The optical surfaces of this setup are protected against dust and humidity outside the aircraft by a quartz window. Orientation of this window is chosen in a way that laser beams reflected on its surfaces cannot enter the telescope.

1.4 Spectrograph

The spectrum emitted in each ground pixel is measured at 12 detection wavelenghts. These wavelengths are set at spectral positions which are specific for water Raman, scattering or the fluorescence emission of substances under investigation (Table 4).

Table 4: Spectrograph

number of channels:	12	discrete, modular
wavelengths/nm	344	H_2O Raman scattering with 308 nm excitation
	330/365/380	Raman baseline, oil and gelbstoff fluorescence
	440 nm	H_2O Raman scattering with 382 nm excitation
	410/470 nm	Raman baseline, oil and gelbstoff fluorescence
	500/550/ 600/650	oil and gelbstoff fluorescence
	685	chlorophyll fluorescence
wavelength selection	dichroic splitters, interference and blocking filters, bandwidth 10 nm typ.	
optical bandwidth	10 nm typ.	
detectors	head-on PMT, range gated	
A/D conversion	12 channel gated integrator, 11 bit	

The detection channels consist of individual modules which are integrated into the detector unit in the form of two rows of 6 modules each, Fig. 4. the UV portion of the telescope output beam is reflected to the first row by use of a long wave pass mirror. The second row of modules has detection wavelengths in the visible region.

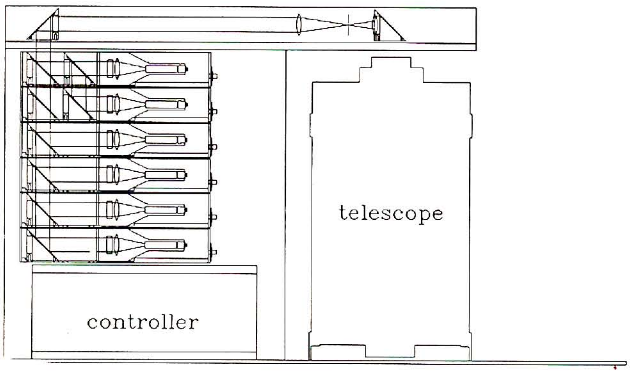

Fig. 4 - Scheme of the detector unit with telescope (right side), mounted above the folding and scanner mirrors not shown in the graph (see Fig. 1 for comparison), and one row of detector modules (left side), each equipped with a dichroic beam splitter for reflecting the relevant por- tion of the spectrum to an interference filter, a quartz lens and a photomultiplier. The controller is a VME-Bus computer for sensor control, and for data interpretation.

High voltage for each PMT is set under software control. PMT gain and the overall sensitivity of the detection channels are calibrated by a short arc flashlamp with a known emission spectrum. From the flashlamp output a path of rays is derived with an orientation which is identical with the telescope output beam.

Sensitivity of the PMT is actively gated by switching the potential of dynodes. The pulse used for PMT gating is derived from a measurement of the time elapsed between laser firing and signal return. This information serves also to correct the intensity of the measured spectra for variations of the distance to the ground pixels.

The detector modules are identical except for the specific choice of the short wave pass mirror which reflects the relevant spectral part of the telescope output into the direction of the PMT. Each module is also equipped with an individual sets of blocking and interference filters for the given detection wavelength. At least 50% of the telescope output intensity is available after wavelength selection with the short wave pass filters whose sharp cutoff characteristic provides a good transmission efficiency of the optical setup. Transmission of the interference filters varies between 10 and 50 %, depending on the wavelength. This provides, together with the high PMT gain, a sufficient signal output intensity required for a single shot data analysis.

The output signals of the detector modules are integrated by a CAMAC 12 channel gated integrator. This is done for the laser-induced fluorescence return. A further signal integration is done a half millisecond later for measuring the daylight background.

The modular structure of the spectrograph allows an easy and economic change of channels in case of defective components. Moreover, a modification of detection wavelengths for particular applications is rapidly accomplished by changing the filter set, or the entire module.

1.5 Computers

Sensor control and calculation of the thickness of surface slicks, and classification of substance types, are made by two VME-Bus processors which are integrated into the detector unit of the optical setup (Fig. 4). A separate operator console serves to display the data on a CRT monitor and to store the raw data together with the navigational information on an optical disk. A few details of these components are given in Table 5.

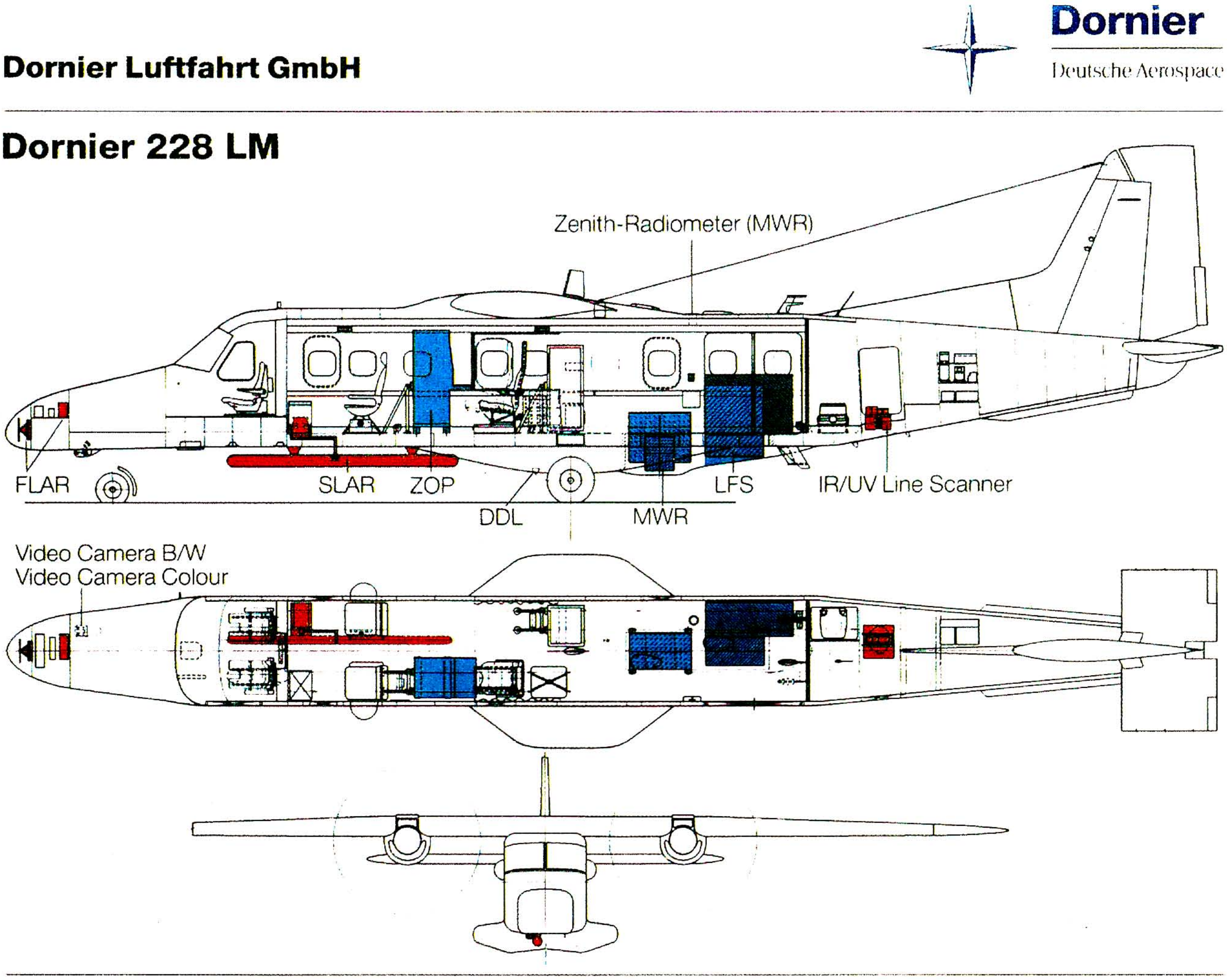

Fig. 5 - Scheme of the 2nd generation Maritime Surveillance Aircraft which will be put into operation in early 1991. The Side-looking and Forward-looking Airborne Radar (SLAR, FLAR)), UV/IR Line Scanner, and the TV cameras are taken over from the lst generation DO 28 aircraft. Central Operator Console (ZOP) and Data Down Link (DDL) are new components. The newly developed Microwave Radiomemter (MWR) and the Laser Fluorosensor (LFS) will be ready for aircraft integration in late 1992. The graph is made available by Dornier German Aerospace, Friedrichshafen, Germany.

Table 5: Computers

VME-Bus, 68020 processor, 16 MHz:	
sensor control	component of detector unit: selection of lasers and detectors, control of measuring cycle, film thickness estimation
classification	component of detector unit: identification of substances
image processing	component of central operator console: images of LFS ground pixel distribution, evaluation of multisensor imagery, data storage on streamer or optical disk.

The mechanical structure of the operator console is identical with the Central Operator Console (ZOP) of the 2nd generation Maritime Surveillance System (Fig. 5). The ZOP, also developed by Krupp MaK Maschinenbav, Kiel, allows the control of the remote sensing and avionics equipment by a single operator.

2. ACTUAL STATUS AND OUTLOOK

A first integration of the laser fluorosensor into a DO 228 research aircraft was done in October 1990. After detailed mechanical and electronic tests on the ground the qualification of the instrument for aircraft use was achieved, and the function was demonstrated in a first test flight.

A first airborne campaign was performed in April 1991 with hydrographic measurements in the German Bight, and with measurements over small oil slicks. The oils were brought out with a quantity of about 60 litres per nautical mile, corresponding to the upper limit of discharges in the open sea according to the MARPOL regulation. Interpretation of the data is in progress.

Development of the prototype version of the laser fluorosensor will be ready in late 1991. Integration of an operational version, which will be qualified for a continuous operation in maritime surveillance, is anticipated for late 1992.

ACKNOWLEDGEMENTS

Many people of the mechanical and electronical workshops at the University of Oldenburg are involved in the development of the laser fluorosensor. We are particularly grateful to Mr. Bottcher and Mr. Brandorff, and their co-workers. Many electronic components have been developed by the engineers of our working group, Mr. Braun and Mr. Nurnberg.

We wish to express our thanks to our industrial partner Krupp MaK Maschinenbau GmbH, Kiel. We are particularly grateful to Mr. J. Chr. Jensen and Dr. A. EBlinger and their co-workers, Mr. Tilgner and Mr. Rathsack.

Aircraft integration and flight test of the instrument are supported by Mr. H. Finkenzeller and his colleagues from the Flight Department of the German Aerospace Research Establishment DLR, Oberpfaffenhofen.

Development of the laser fluorosensor is financed by grants of the Bundesministerium für Technologie. We thank Dr. H.J. Kraege and Dr. W. Schott (BMFT), and Mr. O. Krause from DLR Projekttragerschaft Umweltschutztechnik, Bonn, for their continuous support and encouragement.

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