Wehrtechnische Dienststelle 71

Forschungsbereich
für Wasserschall und Geophysik

C r u i s e R e p o r t

r/v ELISABETH MANN BORGESE

Cruise-No. EMB 112

This report is based on preliminary data

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1. **Cruise No.:** EMB112

2. **Dates of the cruise:** from 10.09.2015 to 21.09.2015

3. **Particulars of the research vessel:**
   Name: ELISABETH MANN BORGESE (EMB)
   Nationality: Germany
   Operating Authority: WTD71; Forschungsbereich für Wasserschall und Geophysik

4. **Geographical area in which ship has operated:**
   Sognefjord, Norway

5. **Dates and names of ports of call**
   from Sunday, 13th, (first entering) to Friday, 18th, (last leaving) of September 2015 daily entering and leaving of port of Høyanger, Norway.

6. **Purpose of the cruise**
   The purpose of the research cruise *coolFLAME2015 is* to improve the scientific understanding of flow noise generation and reduction from turbulent boundary layers in the near-field of mechanical structures. The research is embedded in a European project and is based on results obtained from the preceding sea trials *yellow*FLAME2013 (EMB056) and *blazing*FLAME2014 (EMB084).

7. **Crew:**
   Name of master: Uwe Scholz
   Number of crew:

8. **Research staff:**
   Chief scientist: Dr. Jan Abshagen

   Scientists: Dennis Küter

   Engineers: Jörg Schulz, Kai Haacks, Markus Jäckel

   Technicians: Tim Richter, Klaus Balzer

9. **Co-operating institutions:** University of Kiel (Germany), University of Nürnberg-Erlangen (Germany), INSEAN (Italy), FFI (Norway), Atlas Elektronik (Germany)

10. Scientific equipment

- Towed Body (FLAME) for measurements of flow-induced noise at towing depth between 70 m and 200 m
- Freely drifting buoy with underwater sound transducer for sensor calibration of the FLAME towed body
- CTD on-board EMB for measurements of sound speed profiles

11 General remarks and preliminary results

11.1 Introduction

Figure 1: R\V ELISABETH MANN BORGESE in Høyanger fjord, Norway, during research cruise *cool*FLAME2015 in September 2015.

After *yellow*FLAME2013 in 2013 [1] and *blazing*FLAME2014 in 2014 [2] the research cruise *cool*FLAME2015 was the third sea trial with R\V ELISABETH MANN BORGESE (EMB) and the FLAME towed body. A picture of EMB in Høyanger fjord, a northern lateral branch of Sognefjord, is shown in Fig. 1. The sea trial was conducted in the period between 10.09. and 21.09.2015. The towing experiments took place in Sognefjord, Norway, between 13^{th} and 18^{th}, i.e. on six days of measurements. The FLAME (**FL**ow Noise **A**nalysis and **M**easurement **E**quipment) towed body was designed for flow acoustics measurements under deep water conditions [3].

*cool*FLAME2015 is embedded in the research program of WTD71-FWG and was conducted, after *yellow*FLAME2013, as the second sea trial of an European project with partners from Italy, Norway, and Germany. The general scientific aim of this cruise was to improve the understanding of flow noise generation and reduction near mechanical structures excited by a turbulent boundary layer. The scientific issues addressed with this research cruise are based on the scientific results from numerical and laboratory studies as well as from the two preceding research cruises [4]. Measurement concept, procedure

and equipment for the flow-acoustic underwater experiment were identical to that of *yellowFLAME*2013 [1] and *blazingFLAME*2014 [2]. Only an additional flow sensor has been integrated in the FLAME towed body in order to gain information on the boundary layer flow.

11.2 Research Cruise *coo*lFLAME2015

R\V ELISABETH MANN BORGESE (Fig. 1) was loaded and equipped at the Naval arsenal in Kiel on Thursday, 10^{th}, from 8.a.m. until 5 p.m.. It arrived at Høyanger harbour on Sunday, 13^{th}, at 07:30 a.m. after a transit of about two and a half day through the Great Belt, the Kattegat, and the Skagerrak. At Høyanger additional personal boarded by a boat transfer directly after arrival. The towing experiments started on Sunday, 13^{th} immediately after the boarding procedure was finished and were continued on a daily basis until Friday, 18^{th}. The weather during *coo*lFLAME2015 was unsteady, partly with heavy winds and strong rain, but no delays in the measurements occur due to the weather conditions. Small technical problems and a medical incident caused some delay, but this could be compansated by a tighten measurement program. All proposed scientific issues including sensor calibration with a freely drifting buoy could successfully be addressed during *coo*lFLAME2015.

In total 42 measurement runs have been performed with six different configurations in the period from 13.09. to 18.09.2015. A time consuming, but necessary procedure of preparing the following configuration at Høyanger harbour along with a substantial amount of time required for launching and recovering FLAME prohibits the measurement of more that one configuration per day. The general procedure of the towing experiments was identical to that of the preceding research cruises [1, 2].

The FLAME towed body was launched in Høyanger fjord at a sheltered position and towed at small cable length with a speed of about four knots towards Sognefjord. More towing cable was released when R/V ELISABETH MANN BORGESE crossed the 500m depth contour. Only a single cable length of 400m was used during *coo*lFLAME2015 for the measurements. With a maximum towing speed of 10 knots this resulted in towing depths of the towed body between 70m and 150m. After the measurements were finished the FLAME towed body was recovered. Afterwards the configuration for the following day was prepared at Høyanger harbour. Details of the launching and recovery procedure can be found in [1,2]. On Wednesday, 16^{th}, a freely drifting buoy was launched and recovered in Sognefjord before and after the FLAME towed body, respectively. Below a detailed schedule is given:

Date	Habour	Leaving	FLAME launching	Config.	Runs	FLAME recovering	Entering
10.09.	Kiel	1700				-	(0800)
11.09.	-		-			-	-
12.09.	-	-	-			-	-
13.09.	Høyanger	-	0900	1	8	1530	1610
14.09.	Høyanger	0730	0900	2	7	1424	1510
15.09.	Høyanger	1200	1237	3	5	1623	1800
16.09.	Høyanger	0730	0931	4	9 (5)	1508	1700
17.09.	Høyanger	1200	1240	5	7	1634	1720
18.09.	Høyanger	0700	0834	6	6	1307	-
19.09.	-	-	-	-	-	-	-
20.09.	-	-	-	-	-	-	-
21.09.	Kiel	(0930)	-	-	-	-	0800

After the measurements were completed on Friday, 18^{th}, the FLAME towed body was recovered and R\V ELISABETH MANN BORGESE started the return journey at about 1 p.m.. It entered the Naval arsenal in Kiel on Monday, 21^{st}, at 8 a.m., where it was unloaded.

12 CTD measurements

CTD measurements provide insides into the stratification of Sognefjord. They allow to locate the thermocline and to identify the optimal towing depth, where a low mean current and a low degree of oceanic turbulence can be expected. Such a layer is not only preferable for flow acoustic measurements because of a low degree of inflow turbulence, but it also enables an undisturbed motion of the FLAME towed body on a straight track during the measurements. Furthermore, the sound velocity profile enters directly into the calculations of sound transmission for sensor calibration. CTD measurements at four different stations have been conducted during *cool*FLAME2015 with the CTD measurement system integrated on-board R/V ELISABETH MANN BORGESE. The measurement position was in all four cases located near the centre of Sognefjord south of Høyanger fjord. The exact dates and positions of the CTD measurements are:

Date	CTD Station	Time (UTC+2)	Position	Depth (m)	$\bar{c}$ (m/s)
13.09.	0001	08:14:18	61 08.9902N 5 59.6567E	201.25	1485.48
14.09.	0002	08:17:23	61 08.8046N 5 59.9919E	201.00	1485.16
15.09.	0003	17:04:32	61 09.0693N 5 57.9275E	201.00	1485.17
22.09.	0004	07:36:35	61 08.8940N 5 59.7695E	458.25	1486.47

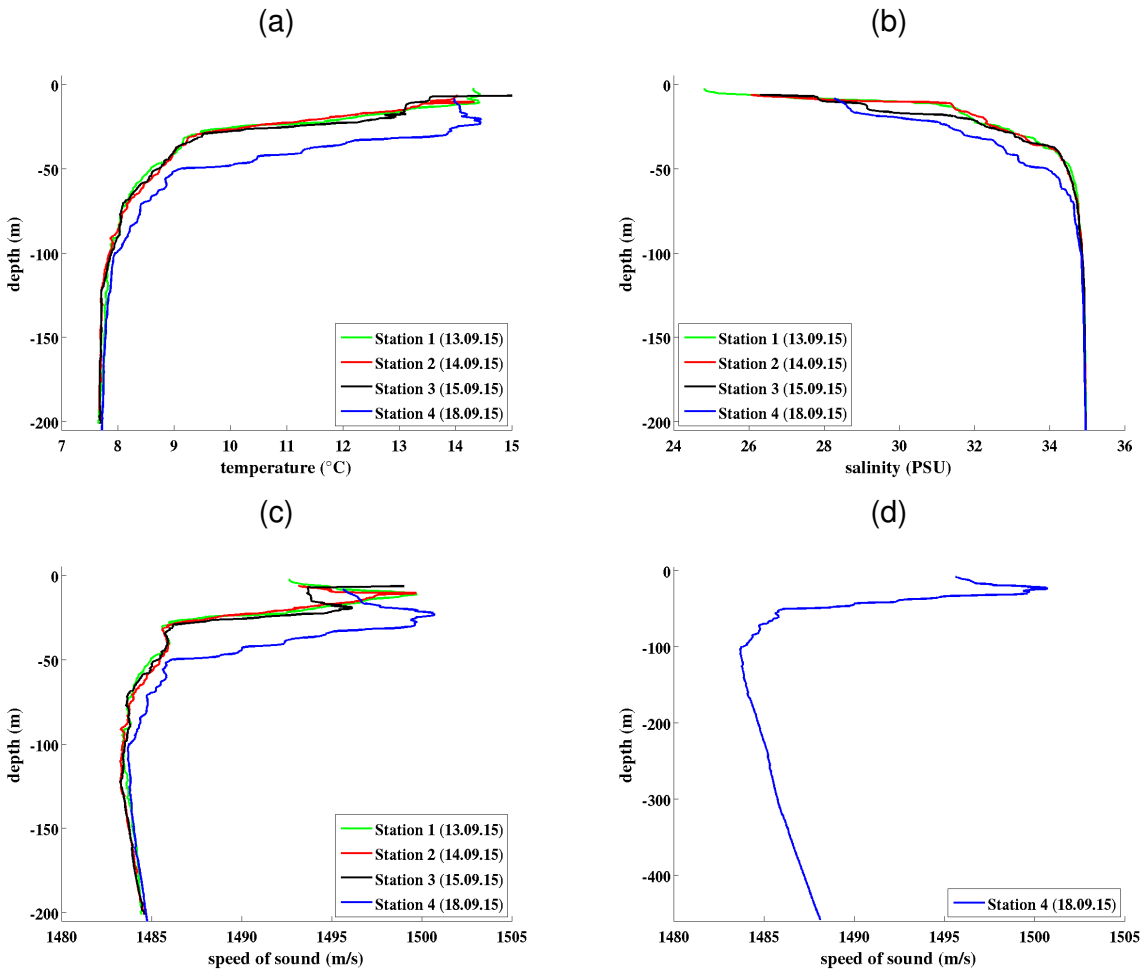

Figure 2: Stratification of central Sognefjord in the area of Høyanger during *cool*FLAME2015: (a) temperature, (b) salinity, and (c) speed of sound. The sound speed profile to a depth of 450m is depicted in (d).

In Fig. 2 the four profiles of (a) temperature, (b) salinity, and (c) speed of sound are shown for depths down to 200m, since this was the intended maximal towing depth. It can be seen that the variability in the stratification on the first three days of measurement (13.-15.09) was low and the thermocline was exceptionally shallow. This can be seen also from the comparison of the profiles measured during *cool*FLAME2015 with those from *yellow*FLAME2013 [1] and *blazing*FLAME2014 [2]. The comparison is depicted in Fig. 3.

Due to the shallow thermocline good conditions for flow acoustics measurements existed already below 70 m during the first half of the sea trial. CTD measurements at station 3 were conducted in the late afternoon of Tuesday, 15^{th}, and can therefore be considered as a reasonable estimation of the sound velocity profile for the calibration on Wednesday, 16^{th}. Due to time constraints a CTD measurement was unfeasible on that day. The final

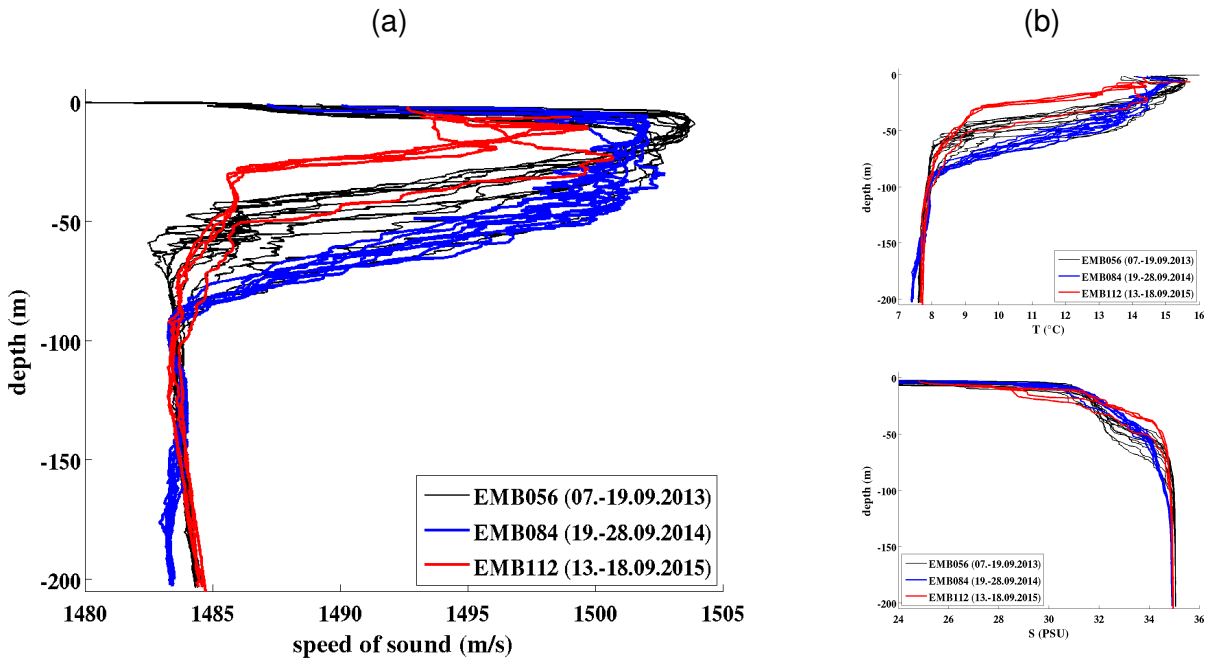

Figure 3: Stratification of central Sognefjord in the area of Høyanger during *cool*FLAME2015 (EMB112, red) in comparison to *yellow*FLAME2013 (EMB056, black) and *blazing*FLAME2014 (EMB084, blue): (a) temperature, (b) salinity, and (c) speed of sound.

CTD measurement on Friday, 18^{th}, (station 4) indicates a shift of the thermocline towards greater depths. Despite of that good conditions for flow noise measurements still existed below 90 m depth. Note, that final CTD measurement was performed down to a depth of 450 m. The corresponding sound velocity profile can be seen in Fig. 2 (d).

12.1 Towing experiments with FLAME

The general procedure of flow acoustic measurements and sensor calibration during *cool*-FLAME2014 was identical to those of the preceding research cruises and more details can be found in [1, 2]. During *cool*FLAME2015 the towing speed was limited to values between U=4. . . 10 knots for all configurations and, for reasons of efficiency, to a towing cable length of L_{cable}=400 m for all runs. The GPS track is recorded for each measurement run and the mean of the speed over ground (SOG) is calculated for each track. A single run typically requires T=360 s of data recording time. Additionally the flow speed of the boundary layer flow was measured with a flow sensor.

A picture of the FLAME towed body with flow sensor during launching is shown in Fig. 4 (a). The GPS tracks of the nine measurements runs recorded on Wednesday, 16^{th}, to-

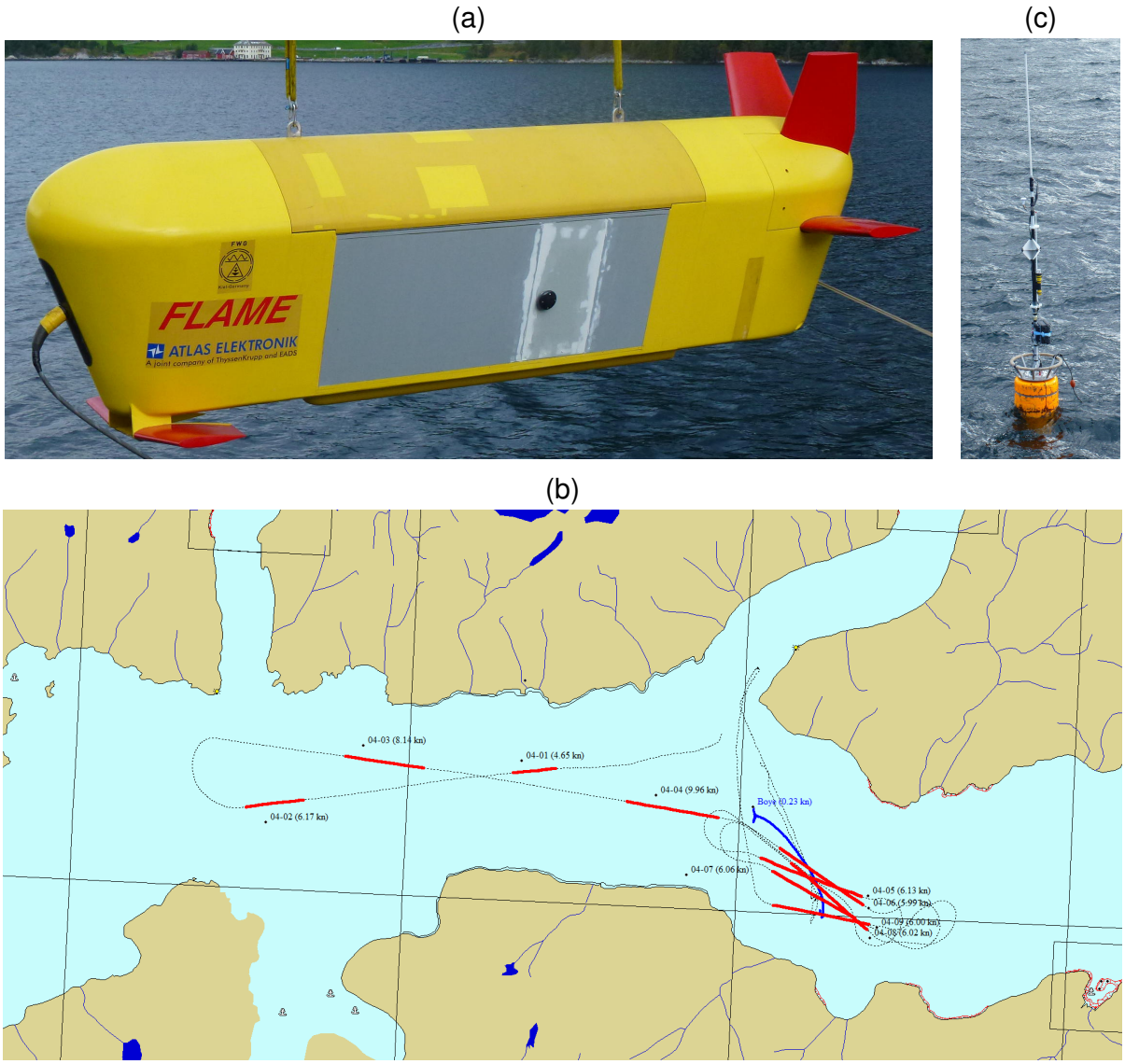

Figure 4: (a) FLAME towed body with flow sensor (black) during *coo*lFLAME2015, (b) freely drifting communication unit of the drift buoy system, (c) GPS track of R/V ELISABETH MANN BORGESE (red/dotted) and of the drift buoy (blue) during measurements on Wednesday, 16^{th}. Four flow acoustic measurements and five calibration measurenents (performed near the buoy) are indicated together with the mean value of the speed over ground during each run.

gether with the corresponding mean value of the SOG are depicted in Fig. 4 (b). On that day four flow acoustic measurements were performed first (04-01. . .04), followed by five calibration runs (04-05. . .09). Flow acoustic measurement runs were typically recorded on long straight tracks in east-west direction, while for the five calibration runs R\V ELISA-

BETH MANN BORGESE passed the drift buoy on a straight track at about 150 m distance at CPA (closest point of approach). The buoy drifted with an average speed of 0.23 knots in south-east direction. A picture of the communication unit of the drift buoy is shown in Fig. 4 (c). It is equipped with AIS, GPS, and radio control.

The transducer operated below the thermocline at a depth of about 90 m. It was mounted to an electronic unit floated slightly below the surface and connected to the communication unit by a cable of about 50 m length. A towing depth of the FLAME towed body of 90 m was achieved by adjusting the speed of R\V ELISABETH MANN BORGESE appropriately. Different types of signals, such as CW-pings and LFM signals between 1-3 kHz, have been used for calibration. Repetition periods of 5 s and 10 s were chosen for signal lengths of 20 ms and 500 ms, respectively, because of reverberation in Sognefjord. The source level of the transducer was 180 dB$_{re\ 1\mu Pa}$.

Acknowledgements

The support from Captain U. Scholz and all members of the crew of R\V ELISABETH MANN BORGESE was again excellent and is gratefully acknowledged.

References

[1] J. Abshagen, Cruise Report, r/v ELISABETH MANN BORGESE, Cruise-No. 06EZ12_EMB056_Abshagen (2014)

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[3] J. Abshagen and V. Nejedl: *Towed body measurements of flow noise from a turbulent boundary layer*, J. Acoust. Soc. Am. **135** (2), 637-645 (2014).

[4] J. Abshagen, D. Küter and V. Nejedl: *Flow-induced interior noise from a turbulent boundary layer of a towed body*, Advances in Aircraft and Spacecraft Science, accepted (2015).