Poster presented at 37th International Liège Colloquium on Ocean Dynamics, Gas Transfer at Water Surfaces, May 02-05, 2005, doi: 10.5281/zenodo.15417

The Heidelberg Aeolotron
New Perspectives for Laboratory Investigations of Small-Scale Air-Sea Interaction

Bernd Jähne, Uwe Schimpf, Günther Balschbach, Christoph Garbe, and Kai Degreif
Institute for Environmental Physics (IUP) and
Interdisciplinary Center for Scientific Computing (IWR)
Ruprecht-Karls-Universität Heidelberg
http://klimt.iwr.uni-heidelberg.de - Bernd.Jaehne@iwr.uni-heidelberg.de -

I. What is Missing with Previous Facilities?

Key chacracteristics of a suitable laboratory facility that allows for a detailed investigation of the mechanisms of small-scale air-sea interaction, especially mass and gas transfer:

- Large fetch and high wave age (even 100 m is short!)
- Homogeneous conditions (for comparison of locally measuring techniques and techniques integrating over the whole facility)
- Inert, chemically clean and gas tight facility for measurements with *trace species*, *surface films*, and *artificial seawater*
- Facility suitable for imaging and infrared techniques

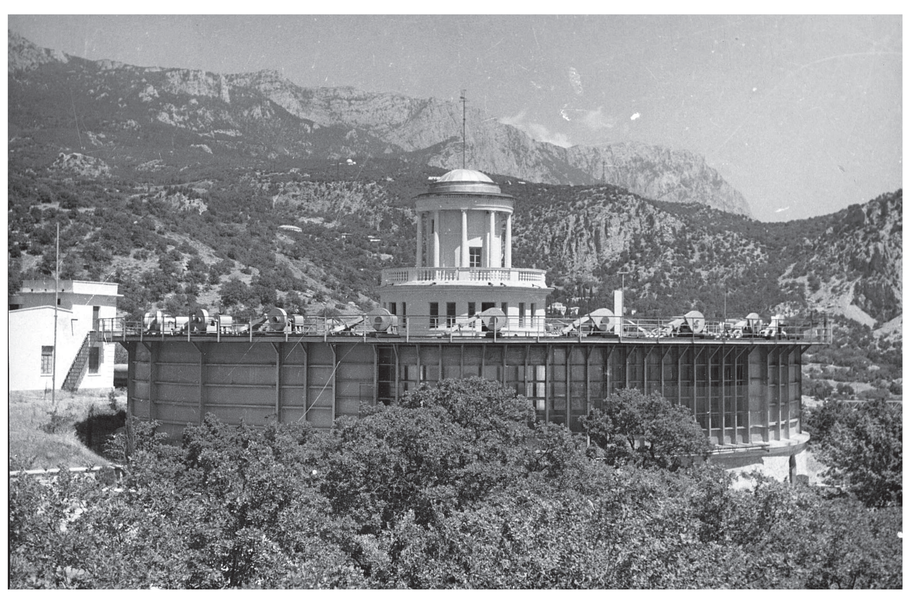
Comparison of Some Air-Sea Interaction Facilities

	KA	UM	W	HH	M	D	SIO	HD1	HD2	HD3
Length (perimeter) [m]	15	15	18.3	24	40	100	40	1.57	11.6	29.2
Width channel [m]	1.8	1.0	0.91	1.0	2.6	8.0	2.4	0.10	0.3	0.62
Outer diameter [m]	-	-	-	-	-	-	-	0.60	4.0	9.92
Inner diameter [m]	-	-	-	-	-	-	-	0.40	3.4	8.68
Max. water depth [m]	0.3	0.38	0.76	0.5	0.8	0.8	1.5	0.08	0.25	1.15
Water surface area [m^2]	27	15	16.7	24	104	800	96	0.16	3.5	18.1
Water volume [m^3]	8	5.7	-	12	83	768	144	0.01	0.87	20.8
Suitable for salt water	-	yes	-	-	-	-	yes	-	-	yes
Use of deionized water	-	-	-	-	-	-	-	yes	yes	yes
Gastight air space	-	yes	yes	-	-	-	-	yes	yes	yes
Control water temp.	-	yes		yes-	yes	-	-	yes	yes	yes
Thermal insulation	-	-	-	-	yes	-	-	yes	-	yes
IR-reflecting walls	-	-	-	-	-	-	-	-	-	yes
Control air temp.	-	-	yes	-	yes	-	-	-	-	yes
Control humidity	-	-	-	-	yes	-	-	yes	-	yes

ID	Facility
KA	Institute for Hydrology, Univ. of Karlsruhe (no longer operational)
UM	RSMAS wind/wave flume, Univ. of Miami
W	NASA Air-Sea Interaction Research Facility, Wallops
HH	Bundesanstalt für Wasserbau, Hamburg
M	IMST, Univ. Marseille, France
D	Delft Hydraulics, Delft, The Netherlands (no longer operational)
SIO	Hydraulic Facility, Scripps Institution of Oceanography, La Jolla
HD1	Small annular facility, Univ. Heidelberg (no longer operational)
HD2	Large annular facility, Univ. Heidelberg (no longer operational)
HD3	“Aeolotron”, Univ. Heidelberg

II. Solution: Large Annular Facility

Annular facility no new idea: Russian facility (“storm basin” with 40 m diameter) built after World War II was operational until 1974 at the Marine Hydrophys. Inst., Sevastopol.



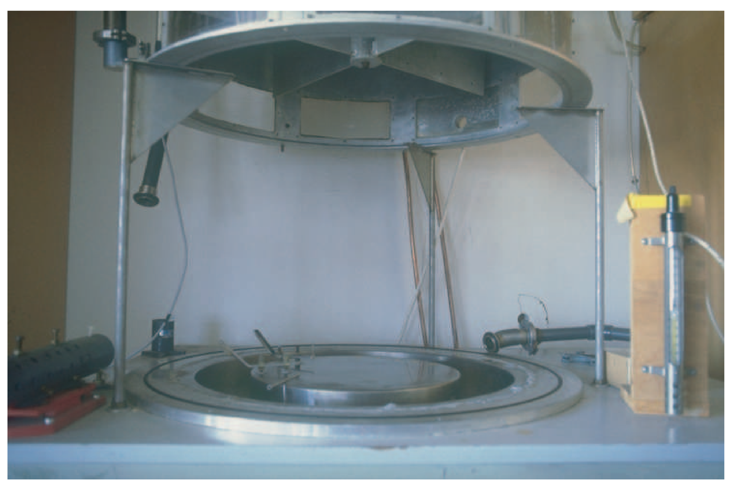
(Courtesy of V. Kudryavtsev, Marine Hydrophys. Inst., Sevastopol, Ukraine)

Advantages and Disadvantages

+ Homogeneous conditions: unbiased comparison of local and spatially integrating measuring techniques
+ Unlimited fetch, wave age only limited by water depth, maximum wave phase speed at 1.2 m water depth 3.4 m/s
+ Independent control of wind speed and gas throughput: enables fast gas exchange measurements
- Secondary flows: disturb logarithmic wind profile but have only insignificant influence on mass transfer
- Influence of curved walls on wave propagation

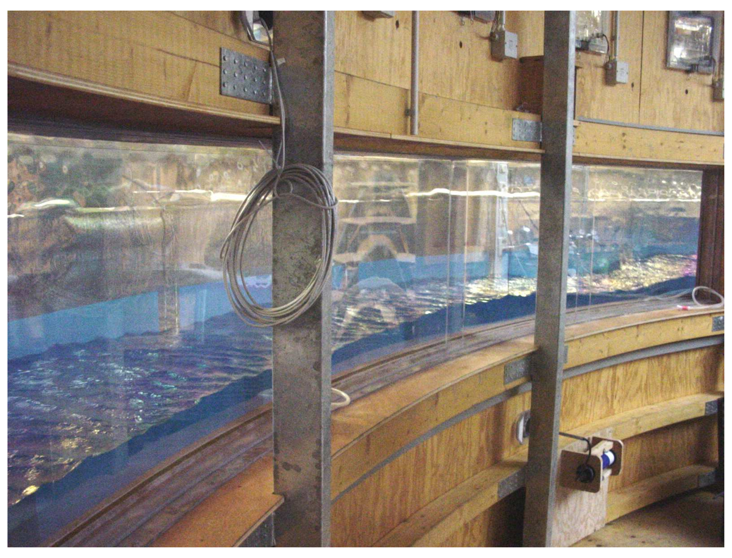
History of Annular Facilities at Heidelberg University

Independent development (without first knowing about the Russian storm basin)



Small circular facility (“Windmill, HD1), designed by founding director of the Institute for Environmental Physics, K. O. Münnich, in 1977 (now part of the institute's museum)

Large 4 m diameter facility (HD2), built in the early ’80ies, in service until 1999



Aeolotron (HD3), 10 m diameter, 0.62 m wide, built 1998–2002

Innovative Features of the Aeolotron

- 10 m outer diameter, annular channel 2.4 m high, 0.65 m wide
- Water depth up to 1.2 m (max. phase speed 3.4 m/s)
- Wind generation by paddle ring, speed up to 15 m/s
- Thermally well insulated system for precise heat flux measurements across the water surface
- Measuring section with large glass plate at bottom for imaging techniques (waves and flow)
- Chemically clean and inert facility; use of deionized water and artificial seawater

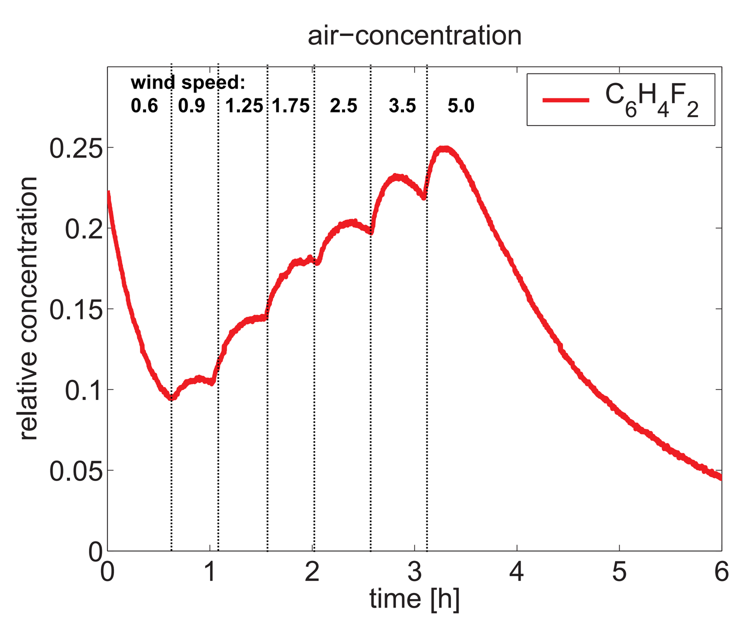
III. Innovative Measuring Techniques

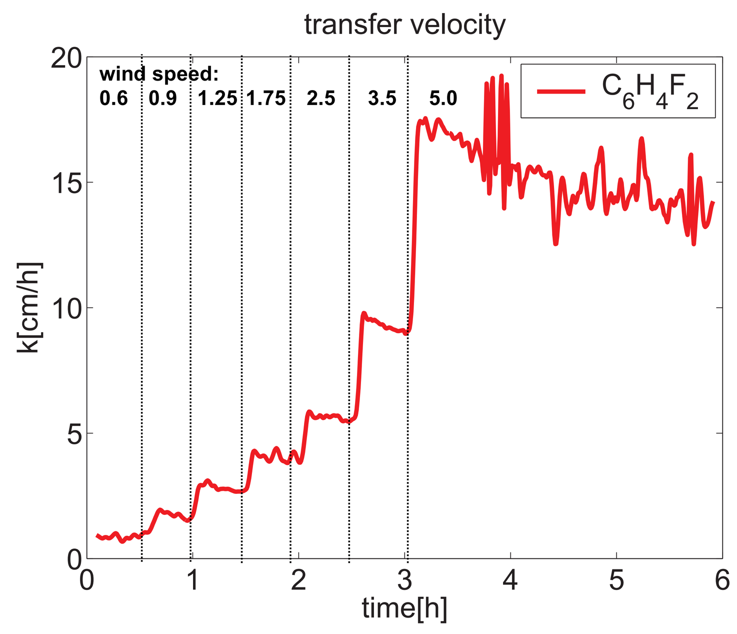
Fast Gas Exchange Measurements: Technique of Controlled Leakage

In the air space flushed with a constant rate Q, mass balance yields a direct estimate of the instantaneous gas transfer velocity:

$$k = \frac{1}{A} \cdot \frac{V_a \dot{c}_a + Q c_a}{c_w (1 - \alpha c_a / c_w)}$$

A	water surface area
V_a	air volume
Q	flush rate
c_a, c_w	air/water concentrations





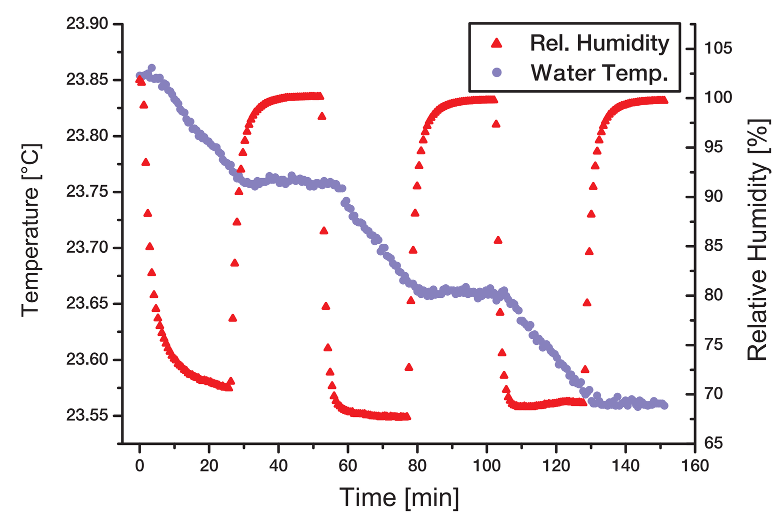
Example: 1,4-difluorobenzene air concentration measured a with low constant air flush rate Q (first graph); transfer velocities computed from previous graph (second graph); wind speed was increased at the dotted vertical lines.

Simultaneous measurements of transfer velocities are possible with at least six tracers: He, H_2, N_2O, CF_2Cl_2, CH_3F, and CH_2F_2 using gas chromatography, FTIR and UV spectroscopy.

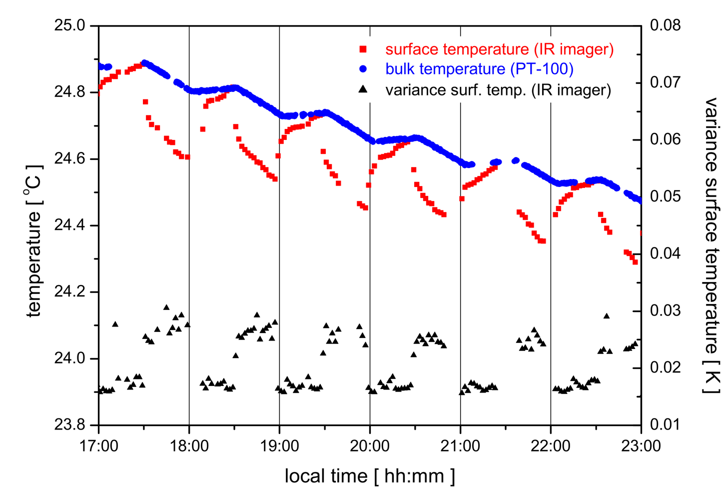
Thermography

Aeolotron ideally suited for thermographic measurements:

- Excellent thermal insulation enables precise calorimetric measurements of heat fluxes
- IR reflecting walls minimize systematic errors in IR temperature measurements at water surface
- Quick switching air conditioning system (air humidity) allows for fast change of net heat fluxes across the water surface



Time record of air humidity and water temperature with periodically flushing dry air into the air space of the Aeolotron.



Time record of the bulk water temperature, mean and variance of the water surface temperature as measured with an IR camera in the Aeolotron.

Simultaneous Wave Slope and Height Imaging

- Telecentric optical system: image magnification does not change with wave height
- Telecentric illumination with LED array for precise slope measurements: wave slope is coded by the position dependent intensity of the light source
- Height measurement by differential light absorption using LEDs with two different wavelengths in the near infrared

(For details see: Jähne B, Schmidt M, and Rocholz R 2004 A new imaging optical technique for combined slope/height measurements of short wind waves *Meas Sci Technol*, submitted)

IV. Conclusions and Outlook

For the next decade measurements are planned to contribute research towards revealing the mechanism of air-sea gas transfer, including the effects of surfactants and waves. The facility is also open for external groups; extra measurement equipment can easily be accommodated.