DEPARTMENT OF THE ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY, CORPS OF ENGINEERS
HANOVER, NEW HAMPSHIRE 03755-1290

June 16, 1986

Applied Research Branch

Mr. Charles E. Smith
Research Program Manager
Technology Assessment and Research Branch
Minerals Management Service
647 National Center
Reston, Virginia 22091

Dear Charles:

The Canadian Climate Centre is undertaking the publication of a Marine Icing Newsletter to "provide a forum for the exchange of information to enhance progress in marine icing research." I've reproduced the copy I received so you could be aware of their activities.

Sincerely,

David Minsk

L. David Minsk
Research Physical Scientist
Applied Research Branch

MARINE ICING NEWSLETTER

Vol.1 No. 1

Canadian Climate Centre June 1986

Following the recent International Workshop on Offshore Winds and Icing at Halifax, October 7-11, 1985, and the Third International Workshop on Atmospheric Icing of Structures held at Vancouver, May 6-8, 1986, it seems appropriate that an attempt be made to try and continue the exchange of marine icing related information fostered by these international gatherings. The marine icing research community is far-flung: Canada, USA, Norway, Japan, Finland, Sweden, Great Britain, USSR, Poland, Germany and Iceland are countries known to have an interest in the marine icing problem. The aim of this newsletter is to provide a forum for the exchange of information to enhance progress in marine icing research.

The Canadian Atmospheric Environment Service has kindly offered the necessary resources to allow me to coordinate and distribute an informal newsletter. Our interest in the newsletter is to help further one of our goals which is to develop a climatological/operational capability to quantify the ice accretion hazard on vessels and offshore structures. In order to be successful, the newsletter will require the active participation of members of the marine icing community. To facillitate production, all contributions should be sent in a format where they can be included directly into the newsletter. Because translation resources are not available, contributions should be in English or French if possible. There will be no set organization to the newsletter as the aim is to provide a very informal forum for the exchange of information. All matters relating to marine icing and the marine icing research community will be welcome, in particular:

- descriptions of research/data collection programs
- case studies of severe offshore icing events
- information on up-coming workshops, symposia etc.
- marine icing forecast programs
- information on up-coming publications
- statements of capabilities
- general news on the location and research activities of members of the marine icing research community.

In this first issue, I have included brief reviews of the two recent workshops mentioned above, and a list of recent publications which have been brought to my attention. Also included is the preliminary distribution list which was obtained from participants at the two workshops. This is by no means complete and a number of countries are not represented, notably Japan and the USSR. I would appreciate hearing about any potential contacts in these areas.

Correspondance should be addressed to:

Ross Brown
Atmospheric Environment Service
Canadian Climate Centre
Hydrometeorology and Marine Division
4905 Dufferin Street,
Downsview, Ontario,
Canada M3H 5T4

Phone: (416) 667-4833

Up-coming/New Literature on Marine Icing:

Zakrzewski, W.P., 1986: Icing of Ships. Part I: Splashing a Ship with Spray. NOAA Technical Memorandum ERL PMEL-66, 74 pp.

Pease, C.H. and A.L. Comiskey, 1985: Vessel Icing in Alaskan Waters 1979 to 1984 Data Set. NOAA Data Report ERL PMEL-14, 16 pp.

Overland, J.E., Pease, C.H., Preisendorfer, R.W. and A.L. Comiskey: Prediction of Vessel Icing. In press, Journal of Climate and Applied Meteorology.

1986/87 Marine Icing Studies at the Canadian Climate Centre:

During 1986/87, the Canadian Climate Centre will be undertaking a comprehensive program of data collection and model development following several key recommendations of the Halifax Workshop. The work carried out includes:

(1) updating and documenting the vessel icing data set resident at the Atmospheric Environment Service,

(2) determining the specifications for rig- and vessel-based field collection programs of sea spray flux information,

(3) developing a sea spray icing model suitable for application to oil rigs and offshore structures,

(4) evaluating currently available rig and vessel icing models for use in Canadian waters,

(5) continuing the Canadian east coast icing monitoring program for offshore rigs and supply vessels started in 1985/86.

The work totals C$50,000.00 and will be contracted out to private industry within Canada. This program is hoped to be continued in 1987/88 with implementation of field programs for collecting sea spray flux information on vessels and offshore structures. The ultimate aim of this work is to develop the capability to quantify the icing hazard for vessels and structures operating in Canadian waters. The 1986/87 program is anticipated to start in July, 1986 and finish by March, 1987.

Recent Workshops:

International Workshop on Offshore Winds and Icing,
Halifax, Nova Scotia,
October 7-11, 1985.

The workshop objectives were:

- to provide a forum for the exchange of ideas and information related to winds and icing offshore, and,
- to identify the needs and concerns of industry, government and the research community in these areas.

15 papers were presented in the four sessions devoted to ice accretion which covered icing case studies, icing models, icing forecasting and measurement of icing and related data. A total of 5 countries were represented including Canada, USA, Norway, Finland and Sweden. Each session was followed by very successful discussions which resulted in a consensus set of recommendations for further work in data collection and model development. These recommendations were included in the workshop proceedings which most of you reading this will have received some time ago. Those wishing to obtain a copy of the proceedings can do so by sending

C$50.00, made payable to the Receiver General of Canada, to the above address.

Third International Workshop on Atmospheric Icing of Structures,
Vancouver, British Columbia,
May 6-8, 1986.

While the main focus of this workshop was on atmospheric icing and its impact on the electrical industry, there were some marine icing papers presented, and some interesting results from the model development point of view. A copy of the conference program is provided along with abstracts for papers of potential interest. Paul Zakrzewski's ship icing model was of particular interest because of his efforts to better describe the characteristics of the spray flux generated by a sea-going vessel. Also of interest was Jean-Louis Laforte's presentation on the microstructural properties of ice accreted from saline water. Persons wanting copies of any of the workshop papers can obtain these from the authors concerned or from myself at the above address.

MARINE ICING NEWSLETTER Vol.1 No.1

Canadian Climate Centre June 1986

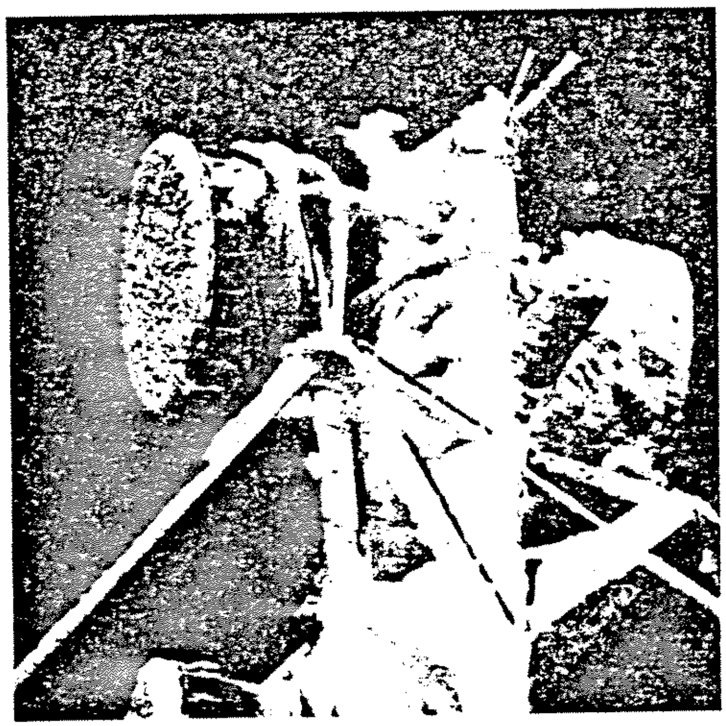
Initial Distribution List:

Name:	Affiliation:
Mr. S. Ackley	Cold Regions Research Laboratory, USA
Mr. T. Agnew	Canadian Climate Centre, Canada
Mr. H. Beal	Atmospheric Environment Service, Canada
Mr. J. Benoit	Mobil Oil Canada Limited
Mr. A. Comiskey	Northern Technical Services, USA
Mr. M. Coolen	Mobil Oil Canada Limited
Ms. M. Danks	Maritimes Weather Centre, Canada
Mr. L. Davidson	Seaconsult Limited, Canada
Mr. A. Earle	Newfoundland Weather Centre
Mr. D. Feit	National Weather Service, USA
Mr. D. Finlayson	NORDCO Limited, Canada
Ms. K. Finstad	University of Alberta, Canada
Dr. E. Gates	University of Alberta, Canada
Mr. I. Horjen	National Hydrotechnical Laboratory, Norway
Mr. O. Houmb	Oceanographic Company of Norway
Dr. T. Jandali	Atmospheric Research Inc., Canada
Dr. R. Jessup	Atmospheric Environment Service, Canada
Mr. S. Jorgensen	Norwegian Hydrotechnical Laboratories
Mr. J-L. Laforte	Universite du Quebec a Chicoutimi, Canada
Mr. J. Launainen	University of Helsinki, Finland
Mr. G. Liljestrom	Gotaverken Arendal AB, Sweden
Mr. S. Loset	Norwegian Marine Technology Research Inst.
Dr. T. Low	KelResearch Corporation
Mr. I. Lowe	National Research Council, Canada
Dr. E. Lozowski	University of Alberta, Canada
Mr. K. MacDonald	Atmospheric Environment Service, Canada
Dr. L. Makkonen	Technical Research Centre, Finland
Mr. C. Mason	Bedford Institute of Oceanography, Canada
Mr. B. Maxwell	Canadian Climate Centre, Canada
Mr. D. Minsk	Cold Regions Research Laboratory, USA
Mr. P. Mitten	Debrocky Seatech(NFLD.) Limited, Canada
Mr. L. Muir	COGLA, Canada
Mr. T. Murphy	Husky/Bow Valley ECP, Canada
Mr. O. Mycyk	COGLA, Canada
Mr. J. Nauman	Minerals Management Service, USA
Dr. J. Overland	NOAA/PMEL, USA
Ms. C. Pease	NOAA/PMEL, USA
Mr. R. Portelli	Concord Scientific Corporation, Canada
Mr. B. Power	Petroleum Directorate, NFLD, Canada
Mr. W. Richards	Atmospheric Environment Service, Canada
Mr. K. Ryan	Canadian Coast Guard
Mr. A. Saulesleja	Canadian Climate Centre

Mr. S. Skey	MacLaren Plansearch Ltd., Canada
Dr. J. Stallabrass	National Research Council, Canada
Mr. V. Swail	Canadian Climate Centre
Dr. B. Weisman	MEP Company Ltd., Canada
Dr. P. Zakrzewski	University of Alberta, Canada

Canadian
Electrical
Association

Third International Workshop on Atmospheric Icing of Structures



Vancouver, British Columbia, Canada
May 6 - 8, 1986

Supported by:

- Canadian Electrical Association (CEA)
- Environment Canada
- B.C. Telephone Co. Ltd.
- Canadian Meteorological and Oceanographic Society (CMOS)
- B.C. Hydro and Power Authority

Workshop Objectives

Ice accumulation on structures is a serious and costly problem affecting a wide variety of industrial and military applications. Many engineers and scientists from diverse fields are working on the problem. For the most part they have been working in isolation.

This isolation was broken when the first international workshop on atmospheric icing of structures was held in the USA in June 1982, and the second in Norway in June 1984. This third workshop aims to reinforce the good work completed in the first two and to:

- confirm and expand international cooperation
- review and update recent progress on atmospheric ice and snow loading
- define goals for future research
- establish a registry of interested participants
- make commitments to research
- provide opportunity for demonstrating meteorological monitoring equipment

Technical Review Committee

Al E. Boyer	Ontario Hydro
Prof. Alan G. Davenport	University of Western Ontario
Beatrice Felin	Hydro Quebec
Douglas E. Franklin	B.C. Hydro Research Div.
Dr. David G. Havard	Ontario Hydro Research Div.
Dr. Samy G. Krishnasamy	Ontario Hydro Research Div.
Dan J. Miletich	B.C. Telephone Co.
David J. Phillips	Atmospheric Environment Service, B.C.
Les E. Welsh	Atmospheric Environment Service, Ontario
David J. Armstrong	Workshop Coordinator B.C. Hydro 970 Burrard Street Vancouver, B.C. Canada V6Z 1Y3 Telephone: (604) 663-2938 Telex: 04-54512

Program

Monday, 5 May 1986

18:00 - 20:00 **Welcome and Registration** — Sheraton Villa Inn

Tuesday, 6 May 1986

07:00 - **Author's Breakfast** — Sheraton Villa Inn

09:00 - **Opening Address —** Mr. Robert H. Stevens, Vice-President, BC Telephone Co. — BC Telephone Co. (Auditorium)

09:15 - **Session 1 - Meteorology**
Co-Chairmen: Les Welsh, Atmospheric Environment Service, Canada; Norman W. Brodie, P. Eng. B.C. Hydro Research Division.

1.1 "Mesoscale Structure of Icing Storms Over the Canadian East Coast and Ontario" by Dr. T.B. Low, Kelresearch Corp.; R.E. Stewart and J.R. Thompson, Atmospheric Environment Service — Ontario, Canada.

1.2 "Ten years of Standardized Field Ice Accretion Measurements in Quebec" by Béatrice Félin, Hydro Québec, Canada.

1.3 "Icing Rates on Sea-Going Ships" by Dr. W. Paul Zakrzewski, Newfoundland, Canada.

1.4 "Measurement of Cloud Droplet Size and Size Distribution With the FSSP and the Rotating Multi-Cylinders" by John B. Howe, Mount Washington Observatory, USA.

1.5 "Observation of Sea Spray Icing at Green Island, British Columbia (1984-1986)" (short contribution) by H.T. (Bob) Beal, AES, and Dr. Tarek Jandali, Atmospheric Research Inc., Vancouver, Canada.

1.6 "Atmospheric Icing", 16 mm movie, 19 minute English commentary by Jean-Francois Gayet, Laboratoire Associé de Méteorologie Physique, France. (short contribution)

12:00 - 13:30 **Lunch** — BC Telephone Co (Cafeteria)

13:30 - **Session 2 - Modelling** — BC Telephone Co. (Auditorium)
Co-chairmen:
Prof. Jean Francois Gayet
Laboratoire Associé de Méteorologie Physique, France
Béatrice Félin, Hydro Québec, Canada

2.1 "Mapping of Snow and Ice Accretion Occurrences From Synoptical Meteorological Measurements" by Bernard Strauss, Méteorologie Nationale, France.

2.2 "Ice Accretion Data for Model Evaluation" by G.C. Castonguay, R. J. Kolomeychuk, Environmental Applications Group Ltd., and Leslie E. Welsh, Atmospheric Environment Service, Canada.

2.3 "Modelling Wet Snow Accretion in a Wind Tunnel" by Y. Sakamoto, CRIEPI, Japan; P. Admirat, EDF/CNRS, J.L. Lapeyre, EDF/ DER, and M Maccagnan, A.A.A., France.

2.4 "An Operational Model for Rime Ice Accretion" by Karen J. Finstad, Professor Edward P. Lozowski, Professor Edward M. Gates, University of Alberta, Canada.

2.5 "The Effect of Conductor Diameter on Ice Load as Determined by a Numerical Icing Model" by Dr. Lasse Makkonen, Laboratory of Structural Engineering, Technical Research Centre of Finland.

2.6 "Meteorological Conditions for Wet Snow Occurrence in France: Calculated and Measured Results in a Recent Case Study on 5 March 1985" by Hervé Gland, EDF, and Pierre Admirat, CNRS/LGGE, France.

2.7 "Extreme Value Analysis of Glaze Ice Accretion in Southern Ontario" by Dr. Samy G. Krishnasamy, Ontario Hydro Research, and R.D. Brown, AES, Canada.

2.8 "Turbulent Dispersion of the Icing Cloud From Spray Nozzles Used in Icing Tunnels" by J. Marek and Dr. William Olsen, NASA, Lewis Research Centre, Ohio, USA.

2.9 "Extended Use of the Icing Model to Estimate Combined Ice and Wind Loads" by Dr. Magnar Ervik and Svein M. Fikke, Norwegian Research Institute of Electricity Supply.

2.10 "Update of Canada's Ice Accretion and Wind Load Modelling for Electrical Transmission Facilities Project", L.E. Welsh, AES, Canada (short contribution)

18:30 - **Formal Dinner** — Sheraton Villa Inn

Host: Mr. Wallace S. Read, P. Eng. President, Canadian Electrical Association

Guest Speaker: Mr. Gordon S. McKay, Past Director-General, Canadian Climate Centre, Atmospheric Environment Service of Canada.

Guests: Mr. Robert H. Stevens, Vice-President, BC Telephone; Dr. Harry M. Ellis, P. Eng. - Director of Research, BC Hydro

Wednesday, 7 May 1986

07:00 - **Author's Breakfast** — Sheraton Villa Inn

09:00 - **Session 3 - Physics of Icing** — BC Telephone Co. (Auditorium)

Co-Chairmen:
Dr. Lasse Makkonen, Technical Research Centre of Finland
Dan J.Miletich, BC Telephone Company, Canada

3.1 "Theoretical Study of the Heat Balance During the Growth of Wet Snow Sleeves on Electrical Conductors" by Jean Claude Grenier, U.S.M.G., Pierre Admirat, EDF/CNRS and Michel Maccagnan, A.A.A., Grenoble, France.

3.2 "The Influence of Several Factors on the Local Heat Transfer From an Isothermal Cylinder" by Roy Narten, Professor Edward M. Gates and Professor E.P. Lozowski, University of Alberta, Canada.

3.3 "Comparison of Droplet Size Measurements by Three Methods" by J.R. Stallabras, NRC, Canada.

3.4 "Microstructure and Mechanical Properties of Ice Accretions Grown from Supercooled Water Droplets Containing NaCL in Solution" by Professor Jean-Louis Laforte and Lise Lavigne, Université du Québec à Chicoutimi, Québec, Canada.

3.5 "Quantitative Results and Proposed Mechanisms on Wet Snow Accretions in the Ishiuchi Wind Tunnel Facilities" by P. Admirat, EDF/CNRS, Grenoble, France; Y. Sakamoto, CRIEPI, Tokyo, Japan; J.L. Lapeyre, EDF/DER; M. Maccagnan, A.A.A., Grenoble, France.

3.6 "Experimental Studies of Ice Accretion on Rotating Wires in an Instrumented Wind Tunnel; by Pascal Personne and Jean-Francois Gayet, Laboratoire Associé de Méteorologie Physique, Université de Clermont, France.

3.7 "Performance Requirements, Design and Operation of the Iowa Icing Wind Tunnel" by Srba Jovic, Dr. Robert Ettema and Dr. John F. Kennedy, University of Iowa, USA.

3.8 "A Wind Tunnel Study of Mechanisms of Sea Spray Icing" by Professor Jouko Launiainen and Markku Lyyra, University of Helsinki, Finland.

3.9 "Use of the LAMP Open Wind Tunnel for Icing Research" (four minute video cassette) by Pascal Personne and Jean-Francois Gayet, Laboratoire Associé de Méteorolgie Physique, France. (short contribution)

12:00 - 13:30 **Lunch**

13:30 - **Session 4 - Icing Data** BC Telephone Co. (Auditorium)
Co-Chairmen:
Stephen F. Ackley, CRREL, USA
Doug Franklin, BC Hydro, Canada

4.1 "Close-Up Movies and Other Experimental Evidence for Modifying the Current Physical Model for Ice Accretion on Aircraft Surfaces" by Dr. William Olsen and Ernie Walker, NASA, Lewis Research Centre, Ohio, USA.

4.2 "A Method by Which Atmospheric Icing is Measured From Mountain-Top Sites" by John W. Govoni, US Army CRREL, New Hampshire, USA; and Alfred Oxton and Kenneth Rancourt, Mount Washington Observatory, New Hampshire, USA.

4.3 "Micro-Processor Controlled Solid-State Anemometer and Ice-Detector" by Charles H. Franklin, Franklin Engineering Co., Michigan, USA; and John B. Howe, Mount Washington Observatory, New Hampshire, USA.

4.4 "Observations of Ice/Water Interactions and Ice Formation on a Model Intake Section in Simulated Cloud Conditions" by Sue J. Downs, Rolls Royce Ltd., Derby, United Kingdom.

4.5 "Development of a Composite Technique in the Determination of the Tensile Strength of Impact Ices" by R.J. Scavuzzo; M.L. Chu and P. Lam, University of Akron, Ohio, USA.

4.6 "Measurement of Adhesive Shear Strength of Impact Ice in an Icing Wind Tunnel" by M.L. Chu; R.J. Scavuzzo, University of Akron, Ohio, USA; and W.V. Olsen, NASA, Lewis Research Centre, Cleveland, Ohio, USA.

4.7 "Ice Observations in Newfoundland and Labrador" by Desmond Butt, Newfoundland and Labrador Hydro, Canada.

4.8 "The Development of a De-Icing Weather Station Which Uses No Heat", The Pneumatic Automatic Weather Station (PAWS), by Ian Strangeways, Institute of Hydrology, Reading, U.K. and Dr. Rick D. Hudson, Polar Tech Ltd., British Columbia, Canada.

4.9 "Application of Electro-Impulse De-Icing (EIDI) to Ice-Covered Structures" by Richard Ross, Ross Aviation Associates; and Glen W. Zumwalt, Wichita State University, USA.

4.10 "Ice-Free Anemometer, Laboratory and Field Testing" by Dr. S.G. Krishnasamy, Ontario Hydro Research; F. Kuja and J. Motycka, Metrex Instruments Ltd., Canada.

4.11 "Current Ice Load Measurements in Norway" by Svein M. Fikke, NVE; and Bjorn Dag Evensen, Statkraft, Norway. (short contribution)

19:30 - Informal Discussion — Modelling. Sheraton Villa Inn (Central 3)
Maximum attendance: 40

Thursday, 8 May 1986

07:00 - **Author's Breakfast** Sheraton Villa Inn

09:00 - **Session 5 - Aerodynamics of Ice-Covered Structures** BC Telephone Co. (Auditorium)

Co-Chairmen: Alan E.W. Ford, Electricity Council, United Kingdom
Dr. Dave Havard, Ontario Hydro Research, Canada

5.1 "Compressive Strength Measurements of Atmospheric Ice" by Jacques Druez, Pierre McComber and Y. Lavoie, Université du Québec à Chicoutimi, Canada.

5.2 "The Numerical Calculation of the Wind Force Coefficients on Two-Dimensional Iced Structures" by Pierre McComber and Gilles Bouchard, Université du Québec à Chicoutimi, Canada.

5.3 "The Growth and Disappearance of Ice Loads on a Tall Mast" by Pertii Lehtonen, Finnish Broadcasting Co. (YLE), Finland; Kari Ahti, Finnish Meteorological Institute, Finland; and Dr. Lasse Makkonen, Technical Research Centre of Finland.

5.4 "An Experimental Study of Aerodynamic Aspects of Wet Snow Accretion on Overhead Lines" by W.T. Eeles, B.D. James and D.A. Castle, Electricity Council Research Centre, United Kingdom.

5.5 "Interaction of Ice and Wind Loading on Guyed Towers" by Professor Alan G. Davenport, University of Western Ontario, Canada.

5.6 "Collection and Reproduction of Natural Ice Shapes on Overhead Line Conductors and Measurement of Their Aerodynamic Characteristics" by Lakis T. Koutselos and Dr. Michael J. Tunstall, Central Electricity Research Laboratories, United Kingdom.

5.7 "Accretion and Shedding of Ice on Cables Incorporating Free Streamline Theory and the Joule Effect" by Dr. J.W. Elliott and Prof. G. Poots, University of Hull, United Kingdom.

5.8 "The Effects of Icing and Wind Loads on a Simulated Power Line" by John W. Govoni and Stephen F. Ackley, US Army CRREL, New Hampshire, USA.

12:00 - 13:30 **Lunch** B.C. Telephone Co. (Cafeteria)

13:30 - **Session 6 - Practical Applications** BC Telephone Co. (Auditorium)

Co-Chairmen: Svein M. Fikke, Norwegian Meteorological Institute, Norway
Professor Alan Davenport, University of Western Ontario, Canada.

6.1 "Wet Snow Management" by Gaston Dumas, ERGH, France; and Y. Sakamoto, CRIEPI, Japan.

6.2 "The Countermeasure of Icing on the Transmission Lines by Conducting Heavy Current" by Masaru Yamaoka, Isao Ohtake, Hokkaido Electric Power Co., Japan; and Goro Wakahama, The Institute of Low Temperature Science of Hokkaido University, Japan.

6.3 "Prevention of Wire Icing by Joule Heating" by Pascal Personne and Jean-Francois Gayet, Laboratoire Associé do Méteorologie Physique, Universite de Clermont II, France.

6.4 "A Study of AC and DC Flashover Performances of Insulators During Ice Accretion" by M. Farzaneh, Université du Québec à Chicoutimi, Québec, Canada; and N. Sugawara, Kitami Institute of Technology, Hokkaido, Japan.

6.5 "Reduction of Tower Head Dimensions Through Galloping Controls" by Dr. Dave Havard and C.J. Pon, Ontario Hydro Research, Canada; and J.C. Pohlman, Consultant, USA.

6.6 "Prediction of Combined Wind and Snow Loads for Overhead Line Designs Using Synoptic Climatological Data" by Alan E.W. Ford, The Electricity Council, United Kingdom.

6.7 "The Combined Ice Plus Wind Loading on Transmission Line Structures" by Dr. Marvin E. Criswell, Ph.D., P.E., Colorado State University, USA.

6.8 "A Utility's Recent Experiences With Devastating Ice Storms and a Program in Response" by T.E. Tymofichuk, Manitoba Hydro, Canada. (short contribution)

6.9 "Communication Tower Icing in the New England Region" by N. Mulherin and Stephen F. Ackley, US Army, CRREL, USA.

17:00 - **Closing Remarks** — Workshop Coordinator

Guest Program

Monday, 5 May 1986

18:00 - 20:00 Welcome and Registration

Tuesday, 6 May 1986

08:30 - Bus leaves for sight-seeing tour of Lower Mainland shopping centres and stops of interest. Your tour guide will be Jane Armstrong. Transportation will be provided by Grayline Bus Tours.

10:30 - Arrive at Expo East Gate. Guests will be free to wander around the Expo site, using their 3-day passes, returning to the East Gate (by the Expo Centre) at 4 p.m.

16:00 - Bus picks up from East Gate and returns to Sheraton Villa Inn.

18:30 - Reception and Dinner at Sheraton Villa Inn.

Wednesday 7 May 1986 — Free

Thursday 8 May 1986 — Free

If you have any special places to visit or people to contact, please get in touch with your hostess, Jane Armstrong at (604) 266-0683 to see what can be done.

Attendance

Name	Organization	Country	Papers	Telephone Number
Ackley, Stephen F.	Cold Regions Research & Eng. Lab.	U.S.A.	5.8,6.9	(603) 646-4258
Admirat, Pierre	Electricité De France	France	2.3,2.6,3.1,3.5	76.48.83.49
Armstrong, David J.	B.C. Hydro	Canada		(604) 663-2938
Asgeirsson, Samuel	The State Electric Power Works	Iceland		91-17400
Bergen, Ray E.	Saskatchewan Power Corporation	Canada		(204) 566-3272
Boyer, Al	Ontario Hydro	Canada		(416) 592-4478
Brodie, Norman W.	B.C. Hydro Research Division	Canada		(604) 590-7468
Brown, Ross D.	Atmospheric Environment Service	Canada	2.7	(416) 667-4955
Butt, Des	Newfoundland and Labrador Hydro	Canada	4.7	(709) 737-1349
Coulombe, Louis	Hydro Québec	Canada		(418) 843-7232
Criswell, Dr. Marvin E.	Colorado State University	U.S.A.	6.7	(303) 491-5606/5048
Davenport, Dr. Alan G.	University of Western Ontario	Canada	5.5	(519) 679-3307
Downs, Sue	Rolls-Royce	England	4.4	0332-42424 X211
Druez, Prof. Jacques	Université du Quebec	Canada	5.1	(418) 545-5466
Eeles, W.T. (Trefor)	The Electricity Council	England	5.4	051-339-4181
Elliott, Dr. John W.	University of Hull	England	5.7	0482-497107
Ervik, Dr. Magnar	Norwegian Research Institute of Electricity Supply	Norway	2.9	47-75-32520
Evansen, Bjorn Dag	Statkraft	Norway	4.11	02-469800
Farzaneh, Masoud	Université du Québec	Canada	6.4	(418) 545-5790
Félin, Béatrice	Hydro Québec	Canada	1.2	(514) 289-5165
Fikke, Svein M.	Norwegian Meteorological Institute	Norway	2.9,4.11	+472605090
Finstad, Karen	University of Alberta	Canada	2.4	(403) 432-5672
Ford, Alan E.W.	The Electricity Council	England	6.6	01-834-2333
Franklin, Charles H.	Franklin Engineering Co.	U.S.A.	4.3	(313) 662-5271
Franklin, Doug E.	B.C. Hydro Research Division	Canada		(604) 590-7440
Fuchs, Werner	G.M.G.O.	W. Germany		09171/83-2190
Gates, Prof. Edward M.	University of Alberta	Canada	2.4,3.2	(403) 432-5180
Gayet, Jean-Francois	Laboratoire Associé de Méteorologie Physique	France	1.6,3.6,3.9,6.3	73-26-41-10
Gland, Herve	Electricité de France	France	2.6	30-71-78-75
Hamner, Jack	B.C. Telephone Company	Canada		(604) 298-7144
Havard, Dr. Dave G.	Ontario Hydro — Research Division	Canada	6.5	(416) 231-4111 X6671
Hesse, Karl	Manitoba Hydro — Distribution Engineering	Canada		(204) 474-4138
Howe, John B.	Mount Washington Observatory	U.S.A.	1.4,4.3	(603) 466-3388/5564
Howland, R.V. (Bob)	Transalta Utilities Corporation	Canada		(403) 267-7570
Hudson, Dr. Rick D.	Polar Tech Ltd.	Canada	4.8	(604) 656-9131
Hulse, Hugh	B.C. Telephone Co.	Canada		(604) 433-8038
Jaakkola, Yrjo	Finnish Broadcasting Corporation	Finland		358-0-401659
Jandali, Dr. Tarek	Atmospheric Research Inc.	Canada	1.5	(604) 926-2583
Jarpenge, Bengt	Swedish Telecom Radio	Sweden		46 8 713 4807
Jonasson, Arni Bjorn	Linuhonnun H.G., Consulting Engineers	Iceland		39120
Jovic, Srba	Iowa Institute of Hydraulic Research	U.S.A.	3.7	(319) 353-3082
Keene, Doug	B.C. Telephone Co.	Canada		(604) 432-4187
Knutsson, Agust	National Power Co. (Landsvirkjun)	Iceland		(91) 686400
Kolomeychuk, Richard J.	Environmental Applications Group Ltd.	Canada	2.2	(416) 968-3684
Koutselos, Lakis T.	Central Electricity Generating Board UK	England	5.6	0372-374488
Krishnasamy, Dr. S.G.	Ontario Hydro — Research Division	Canada	2.7,4.10	(416) 231-4111 X6086
Krokan, Arnulf	Norwegian Telecommunications Administration	Norway		+472788389
LaForte, Prof. Jean-Louis	Université du Québec	Canada	3.4	(418) 543-5403
Laiho, Jorma	Finnish Broadcasting Co	Finland		358-0-4016593
Lapeyre, Jean-Louis	Electricité de France	France	2.3,3.5	47-65-31-27
Launiainen, Prof. Jouko	University of Helsinki	Finland	3.8	358 01912029
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Index of Authors

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MESOSCALE STRUCTURE OF ICING STORMS OVER THE CANADIAN EAST COAST AND ONTARIO

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ABSTRACT

The mesoscale structure of several icing storms in the Canadian Atlantic Region and over Ontario was examined using synoptic, satellite, rawinsonde, radar, and surface information. Precipitation was found to mainly occur in association with frontal precipitation bands. Cold frontal passage itself was commonly associated with a precipitation-free period, implying that these fronts were katabatic in nature. Precipitation amount and type varied with the mesoscale features. Snow, ice pellets, and freezing rain were found to occur in the storms. The simultaneous occurrence of two or more of these precipitation types was often a common situation in icing conditions, rather than the occurrence of any single precipitation type alone.

An icing model was run to evaluate the dependence of accretion on effects due to the mesoscale nature of the freezing precipitation which would produce particles of an ice/water mixture. Forecasting of icing events and their consequences must account for the mesoscale nature of the storms as evidenced by these observations, and by similar observations obtained over southern Ontario.

1. INTRODUCTION

The occurrence of freezing precipitation is a phenomenon which is found only in parts of the world where precipitation can develop within an atmospheric state which exhibits upper level inversions having ambient temperatures exceeding 0°C overlying a lower, sub-freezing region. Regions in which this combination of conditions occur are generally in the mid to extreme latitudes. Within Canada, there are many such areas which experience freezing precipitation, for example, the heavily populated areas of southern Ontario and Quebec. The highest frequency of occurrence, however, is found in the Canadian East Coast. Our examination of weather records from climatological archives have shown a frequency of occurrence for freezing precipitation in Newfoundland (St. John's) to be in the order of 4-5 percent during the January to April period.

A greater insight into the physical properties of these precipitation events could lead to a better understanding of their evolution, the characteristics of the resultant ice accumulations, and perhaps better forecasting of such events. Recent workon the mesoscale structure of winter storms in Canada has resulted in the examination of 8 separate freezing storms, 4 of which occurred on the East Coast. The results of these studies were compared to 4 others which occurred in Ontario.

2. STUDIES OF EAST COAST ICING STORMS

Four East Coast icing storms were examined in order to describe their mesoscale structure during freezing precipitation. These storms occurred on: February 14-16, 1982, December 20-26, 1983, April 6-16, 1984, and February 24-26, 1985. While two of these storms will be described in more detail here, the remaining two will be discussed in terms of the detailed cases.

The first of these is recognized as the storm which led to the tragic sinking of the "Ocean Ranger". During the passage of that storm over Newfoundland, precipitation at St. John's evolved from moderate snow to freezing precipitation, and back to heavy snow again. All of these precipitation were associated with precipitation bands. In particular, the freezing precipitation, which lasted for approximately 2 hours, was associated with a series of very narrow (10-20 km wide) bands as shown in Figure 1. These features were oriented parallel to and located just ahead of the surface warm front.

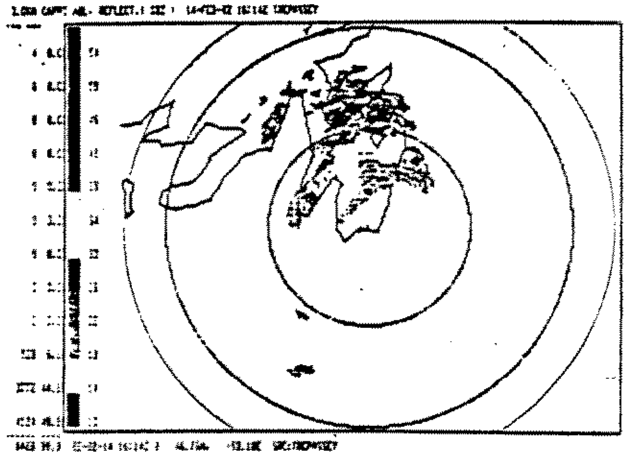

Figure 1. 3.0 km CAPPI of freezing precipitation bands for Feb. 14, 1982 storm.

ICING RATES ON SEA-GOING SHIPS

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ABSTRACT

Icing of medium sized fishing vessels (MFV's) is discussed. To derive the local ice growth rates the heat balance equation of the icing surface is applied. Application of this method to the ice accretion on the ship's superstructure and bulwark is discussed. Formulas of the total icing rates and total ice loads on these parts of an MFV are derived. Based on Soviet data on the distribution of ice over an MFV, the ratios of the ice load on the ship's superstructure and bulwarks to the total ice load on the entire MFV are found. To estimate the total ice load on an MFV for calculated ice loads on the ship's superstructure and bulwarks a simple formula is proposed. This method might be useful in calculating the ship stability.

NOMENCLATURE

a	temperature transfer coefficient of air; also: grid net size
b	grid net size
B	breadth of the bulwark
c_a	specific heat of dry air under constant pressure
c_w	specific heat of water
d	water droplet diameter
D	diffusion coefficient of water vapour in the air
e	pressure of water vapour in the air
f	freezing ratio
h	total thickness of ice deposit
Δh	increment of thickness of ice deposit per hour due to icing (m/hr)
H	height of the bulwark above the deck
i	index of grid cell
j	index of time step
k	coefficient in Eq. (21); number of time steps
L	characteristic dimension (in metres)
L_f	latent heat of freezing
L_v	latent heat of vaporization
Le	the Louis number
$\overline{m}$	local icing rate (kg/m^{2}s)
m^*, m^{**}	time-averaged local icing water for the superstructure and bulwarks (kg/m^{2}hr), respectively
$\mathbf{m}^*$, $\mathbf{m}^{**}$	total icing rates for the superstructure and bulwarks (kg/hr), respectively
M^*, M^{**}, M	total ice load on the superstructure, bulwarks and entire MFV, respectively
Nu	the Nusselt number
p	air pressure
Pr	the Prandtl number
q	heat flux
r	number of cells in grid net
R	direct spray flux to an object
Re	the Reynolds number
s	salinity of seawater (‰)
S	surface area of a grid cell exposed to icing
T	temperature
T_a, T_s, T_d	temperature (°C) of air, water film surface and spray, respectively
$\mathbf{T}_d$	spray temperature (°K)
U_{10}	mean surface wind speed (m/s)
U_r	relative wind speed (m/s)
v	velocity
V	ship speed (knots)
W	molecular weight of dry air
X	potential distance of spray flight over an MFV
X_{cor}	actual distance of spray flight over an MFV
ΔX	difference between X and X_{cor}
α	vessel heading angle
α_w	convective heat transfer coefficient of water
β	empirical coefficient in Eq. (14)
ρ_a, ρ_w, ρ	density of dry air, seawater and ice
Θ	freezing temperature
τ	time
σ	Stefan-Boltzmann constant
μ	molecular weight of water vapour; also: dynamic viscosity of air
ν	kinematic viscosity of air

INTRODUCTION

Icing of ships has been investigated because of its effect on ship stability. Studies of ice growth rates are important for operational purposes in order to predict the intensity of icing and the moment of loss of ship stability due to the ice load.

A number of reports on ice accretion rates on ships have been published in the U.S.S.R., Canada and the U.S.A. Among others, Borisenkov and Pchelko [2], Kachurin et al. [4], Panov [11] and Stallabrass [13, 14] developed models of ice growth on

A WIND TUNNEL STUDY OF MECHANISMS OF SEA SPRAY ICING

by

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Abstract

Ice accretion under conditions of large liquid water contents in the air was studied, on the basis of wind tunnel experiments. The goal of the study was to investigate the mechanisms of icing and the characteristics of the ice deposits. Under stationary wet-growth icing on a non-rotating cylinder, the convective heat transfer coefficient, a quantity of primary importance for the ice growth, was found to depend strongly on the liquid water content in the air stream. New theoretical arguments were presented to explain the above. In simulation of marine icing the ratio of ice salinity versus water salinity was found to vary from 0.3 to 0.8 and the observed ice salinity was compared to theoretical estimates. Concerning the practical experiments in wind tunnels, air modification due to evaporation from the water spray was also discussed.

1. INTRODUCTION

In spite of the substantial efforts |1|, |2|, |3|, |4|, in understanding and modelling of the ice accretion on structures, the models developed so far seem to be unsatisfactory, especially in the wet growth icing. In addition to a general modelling complexity this is due to lack of relevant experimental data and insufficient theoretical arguments.

A wind tunnel was constructed in Helsinki (Finland) in 1982 for studies of ice accretion. This outdoor tunnel was constructed especially for wet growth icing tests. On the basis of the winter time experiments during 1982-1986, the mechanisms of icing were studied; form and size characteristics of the deposits, heat transfer, quantitative ice growth and salinity, as well as special features resulting from salt in marine icing. The adhesion strength of ice on structures was also investigated. Results of these studies have been reported earlier in |5| and |6|.

Three main topics related to icing and icing studies are discussed in this paper. The first one, the modification of air in the tunnel due to evaporation of the water spray injected, is connected with wind tunnel installations. The second one, the convective heat transfer coefficient, a quantity of primary importance from the point of view of the quantitative ice growth, is considered theoretically on the basis of the experimental results. Finally, results of the salinity of ice, especially important from the point of view of the adhesion strength of ice on structures in marine icing are presented and compared with theoretical estimates.

2. EXPERIMENTS

Figure 1 depicts the wind tunnel, which has total length of 7.5 m. The distance of the water spray nozzles (two vertical nozzles) from the test object is 3.5 m. The diameter of the main tube is 1.0 m and that of the test chamber 0.70 m. The 15 kW motor and the axial fan are capable of producing wind speeds from 5 to 28 m/s. The wind speed can be adjusted, but because of the outdoor wind tunnel, the air temperature and humidity cannot be regulated. The air temperature is measured both outside and inside the tunnel; a temperature sensor is located inside the tunnel close to the spray nozzles and it measures the upstream temperature in "dry" air.

The water spray in the tunnel is produced by water and air passing the nozzles. The pressure values for different water flow rates were chosen so that the median volume diameter (MVD) of the droplets (according to the nozzle manufacturer) was approximately 60 µm. The liquid water content and its distribution in the air were calibrated against wind speeds and pressure adjustments by using a rotating cylinder |7| of

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ICE ACCRETIONS GROWN FROM SUPERCOOLED WATER DROPLETS CONTAINING NaCl IN SOLUTION.

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This investigation compares some characteristics of ice accretions grown from fresh water droplets to those of ice accreted from droplets containing small NaCl additions, simulating sea spray icing. Ice accretions were built up in a cold room at -18°C, on a 3.1 cm diameter horizontal cylinder, from 118 µm mean volume diameter supercooled droplets containing up to 2.0% NaCl. Wind velocity and liquid water content were kept constant at 4 m/s and 3.2 g/m³, respectively. The results obtained show that addition of NaCl to water forming ice accretions greatly lowers adhesive and strength properties. It was also found that the density of ice deposits grown under these conditions increases slightly with increasing NaCl content of the water, rising from 0.82 with pure water to 0.91 with 2.0% NaCl brine. Thin section observation shows that ice crystals in deposits grown from brine solutions are equiaxial, while by comparison, crystal in accretions of pure water are elongated in the growth or radial direction. These observations may be interpreted as being due to rejection of NaCl from ice during the freezing of droplets. These results, although preliminary, may be useful in distinguishing between ice formed from sea spray and atmospheric ice accretions.

INTRODUCTION

Ice accumulation on ships and stationary structures in the marine environment can cause severe accidents, loss of human life and important material damages. Therefore, ship icing has long been recognized as a serious hazard. According to previous research (1-3), the main cause of ship icing in Arctic sea regions is spray, which alone accounts for 50% of all cases; spray combined with atmospheric icing accounts for an additional 41% of ship icing. Icing attributed to fog droplets and to precipitation alone occurs rarely (3 and 6% respectively). During an icing storm, spray icing and atmospheric icing are often observed simultaneously, and are not usually distinguishable because these types of ice generally produce the same problems. Sea spray may be generated in three ways (4): by vessel movement through the water; by waves striking against a stationary structure; and by water droplets wind-blown off wave crests. Analysis of icing reports (5) indicates that several conditions must occur simultaneously for spray icing to built up on a structure or ship. These conditions are related to wind speed, air temperature and salinity; but wave steepness and current direction also play a role.

The purpose of the present work is to compare some characteristics of ice accretions grown from fresh water droplets to those of ice containing small NaCl additions. The strength properties and the crystal texture are studied using various ice samples grown under conditions close to those commonly prevailing during sea spray icing.

EXPERIMENTAL PROCEDURE

Ice accretions are grown on a smooth aluminium cylinder, 3.15 cm in diameter, placed horizontally in a 4.8 m x 2.8 m x 3.5 m cold room, where a minimum temperature of -35°C ± 0.5°C may be obtained. Supercooled droplets are produced by two spray nozzles located 1.8 m in front of the aluminimum conductor (Fig. 1). Tap water solutions containing between 0.3 and 2.0% NaCl, and 30‰ sea water are supplied to the nozzles from a large reservoir at a room temperature.

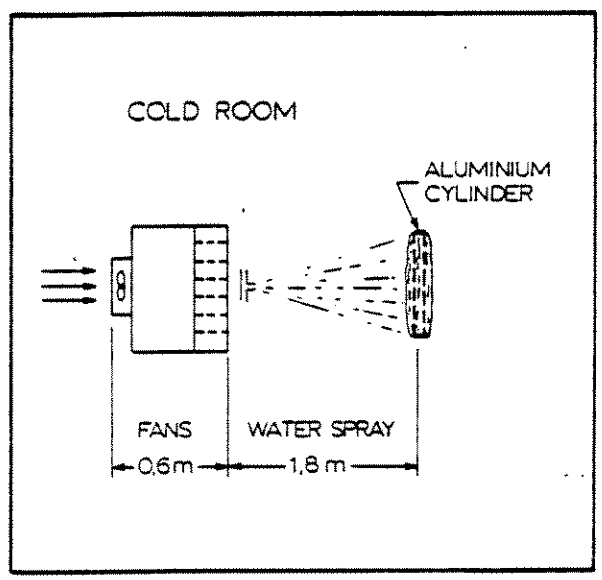

Figure 1 : Schema of experimental set-up, showing relative position of fans, sprays and cylindrical collector.

In the present series of tests, air temperature, wind velocity and liquid water content are kept constant at -18°C, 4 m/s and 3.2 g/m³ respectively. The mean volume diameter of the droplet spectrum, measured using the silver colloid film method (6), is 118 µm (Fig. 2). The liquid water content (w) of the air is measured by the single cylinder method (7). In order to obtain a uniform air velocity profile, the wind is produced by 2 fans placed behind a rectangular block containing small tubes. These growth conditions are chosen within the capabilities of the existing spray-producing facility of our experimental set up, and are felt to represent conditions that could occur in nature.

Before each experiment, the conductor is carefully cleaned with hot water and soap; it is further

COMPARISON OF DROPLET SIZE MEASUREMENTS BY THREE METHODS

J.R. Stallabrass, National Research Council of Canada

Measurements in an icing wind tunnel of the droplet size distribution made with a Forward Scattering Spectrometer Probe (FSSP), an oiled slide impactor, and a soot slide gun show considerable discrepancies between the various methods. The FSSP measurements showed the greatest consistency in relation to the spray nozzle settings, while the soot slide gun was the least consistent. This inconsistency is believed to be, to a large extent, the result of the smaller sample sizes involved.

When compared on the basis of the median volume diameter (MVD) the oiled slide and the soot gun results compared more favourably with each other than with the FSSP results. Except for MVD's of about 10 micrometres, the FSSP results were significantly lower than those of the other methods. This appears to be the result of occasional large drops observed by the impactor methods, but too large to be sampled by the FSSP, emphasizing the importance of ascertaining that the appropriate characterization of the spectrum is being used when comparing different methods of droplet size measurement.

INTRODUCTION

The standard method used for over 30 years at the National Research Council of Canada for the measurement of the droplet size distribution in sprays and clouds has been the Oiled Slide Method(1). This method has been used, not only in the icing wind tunnels and engine test cells, but also from aircraft involved in icing and cloud physics research. Disadvantages of this method were the fact that the samples had to be recorded by photomicrography within seconds of sampling to minimize evaporation from the droplets embedded in the oil film on the slide, and the tediousness of sizing and counting the resulting droplet images on the photograph.

However, the equipment required is inexpensive and the results were considered to be of adequate accuracy as long as the sample contained a sufficient number of droplets (usually about 1000) and, where necessary, collection efficiency effects were taken into account. If some of the smallest droplets in the spectrum were lost in the sampling, or not taken into account in the analysis, it was of little account in an icing context, since they contributed little to the overall rate of icing, or to the median volume diameter (MVD) of the droplet spectrum. The MVD provides that single statistical measure that best characterizes the droplet distribution for icing work.

With the advent of sophisticated laser measuring devices, some workers(2,3,4) began to question the accuracy of the oiled slide method, suggesting that it overestimated the MVD by a factor of about 1.6 on the assumption that the laser devices were giving true measure of droplet size. We were rather skeptical until some tests we made on the icing of rotating cylinder(5); these showed lower icing rates than those predicted by an icing model when the collection efficiency was calculated using the oiled slide measurements. We discarded the idea that the collection efficiency data of Langmuir and Blodgett(6) could be materially wrong, and decided that we should do some comparative droplet sizing tests of our own.

We borrowed a Particle Measuring Systems' (PMS) Forward Scattering Spectrometer Probe (FSSP) and also a Soot Slide Gun of the type used by the Australian Aeronautical Research Laboratories(7).

Droplet size measurements were made in the icing wind tunnel using initially the same single spray nozzle that had been used for the cylinder icing tests. Later, tests were made using a different spray nozzle. Because of the small size of the tunnel test section (30 cm square) the FSSP could not be mounted axially in the wind tunnel; so the standard axial sampling tube of the instrument was replaced with one that was mounted perpendicular to the axis, so that the body of the FSSP was situated outside the tunnel [Fig. 1].

MEASUREMENTS USING SMALL SPRAY NOZZLE

For these tests, the FSSP was operated on Range 3 only, i.e. the nominal 2 to 30 µm range. This was done because extensive calibrations of this instrument had been done on this range by the National Center for Atmospheric Research (NCAR)(8), and later by the Atmospheric Environment Service (AES). A summary of these calibrations is shown in Table 1.

Table 1
AES FSSP Channel Definitions (Range 3)
2-30 µm Nominal Range

Channel No.	PMS Limits	Modified Limits	Midpoint	Width
1	1- 3	1.0- 2.3	1.65	1.3
2	3- 5	2.3- 3.2	2.75	0.9
3	5- 7	3.2- 4.9	4.05	1.7
4	7- 9	4.9- 7.4	6.15	2.5
5	9-11	7.4-11.0	9.2	3.6
6	11-13	11.0-13.0	12.0	2.0
7	13-15	13.0-14.8	13.9	1.8
8	15-17	14.8-16.6	15.7	1.8
9	17-19	16.6-19.2	17.9	2.6
10	19-21	19.2-22.6	20.9	3.4
11	21-23	22.6-25.2	23.9	2.6
12	23-25	25.2-27.0	26.1	1.8
13	25-27	27.0-30.0	28.5	3.0
14	27-29	30.0-33.0	31.5	3.0
15	29-31	33.0-35.2	34.1	2.2

THE INFLUENCE OF SEVERAL FACTORS ON THE HEAT TRANSFER FROM AN ISOTHERMAL CYLINDER

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ABSTRACT

The relative influence of surface roughness, free stream turbulence, and cross-sectional shape on the heat transfer distribution around an isothermal cylinder were examined. A laboratory apparatus was constructed to determine the local Nusselt number and its distribution around the upstream half of a cylinder in crossflow. Tests were performed at Reynolds numbers of 40 000, 80 000, and 120 000 to determine the influence of three different sizes of surface roughness on the heat transfer. The effect of free stream turbulence and cross-sectional shape were examined using the results of tests performed by others.

It was difficult to establish the relative effect of surface roughness, due to the limited range of Reynolds numbers examined in the present study. Roughness parameters such as the size, shape, and surface distribution of roughness elements also differed between studies precluding any generalizations about the influence of surface roughness. Results due to others suggest that the influence of surface roughness may produce the largest increase in the heat transfer around a cylinder, especially at higher Reynolds numbers.

Free stream turbulence and shape effects both exhibited the smallest increase in local and average heat transfer. Results due to others indicate that cross-sectional shape or turbulent intensities up to 5% can increase the average heat transfer by 20% to 30% for the upstream half of the cylinder. The influence of shape on the average heat transfer is not large except at higher Reynolds numbers.

NOMENCLATURE

Symbol		Units
a	depth of each strip heater.	[m]
A	exposed surface area of each heater.	[m^2]
b	half the width of the gap between adjacent heaters.	[m]
D	diameter of test cylinder.	[m]
h	local convective heat transfer coefficient.	[$W/m^2 \cdot {}^oC$]
K	thermal conductivity.	[$W/m \cdot {}^oC$]
L	length of the gap between heaters.	[m]
λ_n	+ve roots of $\lambda_n \tan(\lambda_n a) = h/K_s$.	dimensionless
Nu	Nusselt number.	dimensionless
P	electrical power.	[W]
Q	heat flux (total or per unit area)	[W] or [W/m^2]
Re	Reynolds number.	dimensionless
T	temperature	[^oC]

Subscripts

θ	local position (angle) on the cylinder measured from the stagnation line.
a	ambient air.
s	cylinder surface (epoxy material between heaters).
gap	region between heaters at the cylinder surface.
h	electrical heater on the cylinder.
n	nth root, n = 1,2,3,...

INTRODUCTION

An important component of an icing model is the steady state energy balance calculation carried out at the surface of the accretion. This calculation is necessary to determine the freezing fraction and hence the local rate of ice accretion. An energy balance is comprised of many terms including radiation, convection, conduction into the accretion, evaporative heat flux, latent heat flux due to freezing of some or all of the impinging water, and the sensible heat transfer between the impinging droplets and the surface (Lozowski, et.al.[1]). In most icing conditions, the evaporative and convective terms dominate the energy balance; therefore, it is not necessary to account for every term in the surface energy balance to obtain a good estimate of the local ice accretion rate.

The magnitudes of the evaporative and convective heat transfer terms are directly dependent on the value of the local convective heat transfer coefficient (h) at the surface. A measure of the local heat transfer coefficient is therefore required in an icing model to accurately predict the local icing rate on a body. In some cases the quantity "h" can be calculated analytically; however, for most situations the heat transfer coefficient must be determined experimentally. In order to make an icing model time dependent, it is also important to account for any new surface or flow conditions which may influence the magnitude and distribution of the heat transfer coefficient at the surface.

The object of this study was to compare the relative effects of the following three factors on the local heat transfer distribution around an isothermal cylinder:

1. Surface roughness
2. Cross-sectional shape
3. Free stream turbulence

AN OPERATIONAL MODEL FOR RIME ICE ACCRETION

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ABSTRACT

An inexpensive and fast computer model for the prediction of rime ice loads and accretion shapes on cylinders has been developed. The model makes use of newly derived approximations for overall and stagnation line collision efficiencies, which have been designed for the specific physical regime which relates to marine, transmission line and aircraft icing. Parameterizations are used for the distributions of local collision efficiency and local density, as well as to approximate the effect of realistic droplet size spectra. The model is time-dependent and can include slow (e.g., torsional) rotation.

At present, the model is most usefully applied to wind tunnel icing experiments where the meteorological parameters required as input are reasonably well known. The level of local climatological knowledge of these parameters needed to implement such a model in the field is discussed.

LIST OF SYMBOLS

D_d	diameter of water droplet
E	overall collision efficiency
lwc	liquid water content
mvd	median volume diameter of a droplet spectrum
R_c	radius of circular cylinder
T	'tail' length for simulated droplet spectrum collision efficiency curve
U	free stream speed
α	angle between local surface normal and the free stream direction
α_{max}	maximum impingement angle
β	local collision efficiency
β_o	stagnation line collision efficiency
ρ	local rime ice density
ρ_o	stagnation line rime ice density

1. INTRODUCTION

The ultimate aim in studying the icing phenomenon is the prediction of its occurrence, whether of a particular event or of the probability of extreme events. As with other physical problems, there are two approaches one may take towards achieving this aim.

The first is a statistical approach, in which one observes a very large number of events (predictands) as well as their antecedent or concurrent conditions (predictors), and then examines the statistical correlations between predictors and predictands. Considerable computational effort may be required to establish a 'best guess' for the most significant predictors, and for the form of the predictive relation.

The reliability of the outcome is highly dependent on the number and quality of the observations. The advantage of this method is that a predictive relation may be derived and applied in the absence of any further understanding of the physical processes involved, which may be very complex. But if the observations are adequate, and a decent correlation can be found, it is the quickest way of achieving practical forecasting results.

However, its predictive skill is limited by the strength of the discovered correlation, and its applicability is limited to the range of conditions defined by the original observations. For icing studies, this, of course, includes the geographical range, since the character of icing problems has a large regional variability.

The other approach to prediction is that of model-building. This is usually a theoretical mathematical model, which attempts to simulate the intermediate steps, and to understand the causal relationships between the input conditions and the output predictions. Producing such a model does take considerably more time and effort than producing a statistical correlation, and the requirements for the observational data are just as stringent. Furthermore, no model can perfectly reproduce a given physical process or situation - there must always be simplifying assumptions made.

But the knowledge gained from the model is more universally valid, within those assumptions, than is any purely statistical relationship, and may provide important building blocks for more complex models. Even the simplest physical model might at least suggest what the most effective predictors will be for a statistical study; thus if we find that liquid water contents and cloud droplet sizes are of prime importance in determining model ice accretion rates, then collectors of field data should take note, even if these things are very difficult to observe.