Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-98216

Supercooled large droplets in icing conditions

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Abstract

In March 1997 NLR investigated the icing atmosphere for aircraft by flying with an instrumented research aircraft through clouds. Liquid water content, droplet diameter distributions and air temperature were measured. Large droplets were found in air masses with a limited extent. Results from the measurement campaign are presented and compared with limits in aircraft and helicopter certification requirements.

The investigation was made in the framework of a European co-operation in the EURICE project, partially funded by the Directorate General VII for Transport of the European Commission.

Contents

(15 pages in total)

Abbreviations

CIRA	Centro Italiano Richerche Aerospaziali
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
EGS	European Geophysical Society
EURICE	EUropean Research on aircraft Ice CErtification
FAR	Federal Aviation Regulation
FSSP	Forward Scattering Spectrometer Probe
GKSS	Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt
INTA	Instituto Nacional de Tecnica Aeroespacial
JAR	Joint Aviation Regulation
LWC	Liquid Water Content
MED	Mean Effective drop Diameter
MVD	Median Volume Diameter
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium NLR
NM	Nautical Mile
OAP	Optical Array Probe
PDPA	Phase Doppler Particle Analyzer
SLD	Supercooled Large Droplets
UTC	Universal Time Coordinated

1 Introduction

Supercooled large droplets have a lot of attention in the aviation community. Ice accretion on aircraft caused by SLD is different from ice accretion due to small particles, which has implications on the ice protection system performances and safety. In the EURICE project twelve partners co-operate in investigating the aircraft icing certification and the operation of aircraft in icing conditions. One of the objectives of EURICE is to increase the knowledge of atmospheric icing conditions, where special interest is for SLD. For this purpose three research aircraft, from DLR, INTA and NLR, have been flown to measure icing conditions. This report describes results of the NLR flight campaign with respect to SLD.

The certification requirements for aircraft operation in icing conditions are described in JAR/FAR 25/29. The atmosphere in which aircraft icing occurs is characterised in the Appendix C of the document. In the Appendix C of JAR/FAR 25/29 the parameters LWC, MED, (static) air temperature and horizontal extent of the cloud are used as descriptors of the icing atmosphere. The MED in the droplet distribution is defined as the diameter for which 50 % of the Water Content is in droplets smaller than the MED. The MED is defined in icing conditions with assumed distributions of droplet diameters, whereas the quantity MVD is defined identically for a measured droplet distribution. For this study the difference is of no relevance.

In Appendix C the continuous cloud and the intermittent cloud limits are defined, with horizontal extents of 17.4 NM and 2.6 NM. Average LWC and MED over these horizontal intervals are inside the envelopes represented in fig. 1. The complete description of Appendix C is given in ref. 1.

Conditions with a MVD larger than 50 micrometer that have a horizontal extent longer than 2.6 NM, or conditions with a MVD larger than 40 micrometer that have a horizontal extent of more than 17.4 NM are considered as SLD conditions outside of Appendix C. A comparison between measurements and the Appendix C description is given in this report.

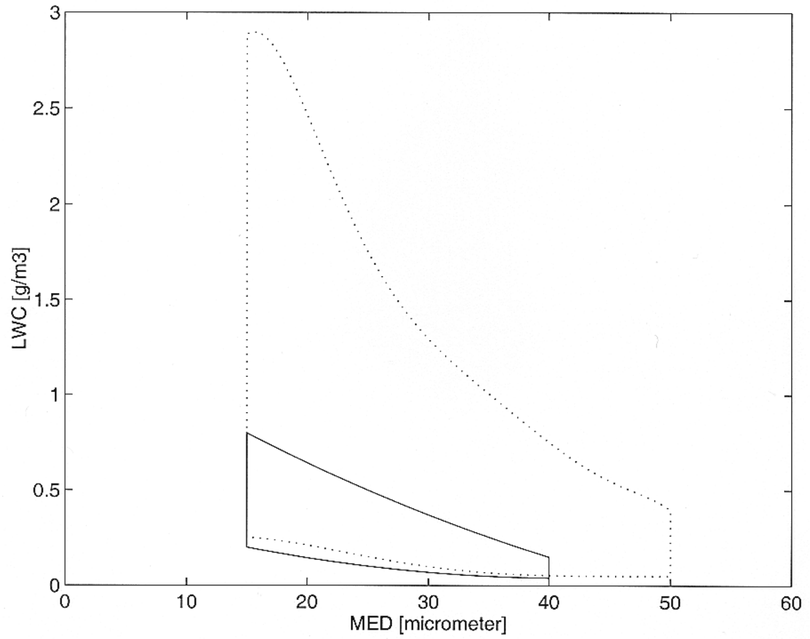

Fig. 1 Envelopes of MED and LWC ranges for the continuous cloud (-) and intermittent cloud (…) limits described in JAR/FAR 25/29 Appendix C icing conditions. Within these envelopes additional limits are set for temperature and altitude.

2 Flight campaign overview

2.1 The instrumented aircraft

The NLR research aircraft for the EURICE flight campaign was a Fairchild Metro II. The instrumentation of the aircraft was enlarged with some cloud physics instruments. Cloud physics instrumentation for measuring droplet size distributions, droplet densities and liquid water content was installed on a pod mounted under the fuselage. An FSSP and an OAP of the German institute GKSS, a Csiro King probe of the Max Planck Insitut für Meteorologie of the University of Hamburg and a PDPA owned by CIRA were installed on the pod. The PDPA operation was managed by CIRA. The results of the PDPA measurements are reported separately.

Fig. 2 The NLR Fairchild Metro II in the EURICE configuration

Fig. 3 The pod with cloud physics instrumentation installed under the NLR research aircraft

2.2 Clouds

The flight campaign was executed during 5 weeks in March and April 1997. Data were gathered in 5 measurement flights. The forecast for icing provided by the local weather office included a moderate to severe icing forecast for each of the days in which data were gathered. Ice accretion on the aircraft was encountered in all flights. The clouds investigated during the first flight were stable frontal clouds and can be characterised as stratiform. The clouds investigated in the other flights contained convection and have a cumuliform character. In this report data of the first flight are presented.

3 Supercooled large droplets

3.1 Measurement results

In Appendix C the parameters liquid water content LWC, MVD, (static) air temperature and horizontal extent of the cloud are used as descriptors of the icing atmosphere. Figure 4 shows the time series of the parameters LWC and MVD calculated from FSSP and OAP data taken in the first flight. One second averages are plotted. No ice crystals were observed in the OAP images which implies that all water can be considered as liquid. LWC values are not large compared with the limits in Appendix C. However, the MVD is during some short periods larger than the 50 micrometer mentioned. The Appendix C horizontal extents of 17.4 NM and 2.6 NM correspond to 340 s and 50 s time intervals respectively at the airspeed flown. Averages over these time intervals were calculated. Conditions with a MVD larger than 50 micrometer which have a horizontal extent longer than 2.6 NM are considered as SLD conditions outside of Appendix C. These situations were encountered in this flight, an example is shown in figure 6 where the extent was much longer than 2.6 NM. Static temperatures of air were close to the freezing point. For the segment in figure 6 the temperature was –1°C and the average LWC was 0.09 g/m3.

3.2 Implications

In the first and the fourth measurement flight the aircraft performance was affected considerably. Drag increased, inducing that the engine power had to be increased to keep the aircraft at the same altitude. The icing conditions were abandoned in these situations as the aim of the research flights was to investigate the atmosphere and not the limits on aircraft performance or the ice accretion. By decreasing the flight altitude, flight was continued through atmosphere above the freezing point and ice melted off.

The ice accretion on the aircraft was observed carefully and recorded on video during the flights. Ice accretion was not observed behind the de-icing boots, even in the flights with SLD. On the contrary, the ice accretion was close to the leading edge of the wing as in fig. 7. The short encounters with SLD did not inflict large effects on the aircraft performance.

4 Conclusions

SLD were found in the atmosphere during short periods, corresponding to a few nautical mile horizontal extent. The extent and the MVD was for some periods such that the conditions should be considered as outside the Appendix C envelope defined for aircraft certification.

5 References

1. Federal Aviation Regulation Part 25 “Airworthiness standards: transport category airplanes” and Part 29 “Airworthiness standards: transport category rotorcraft”, FAA, Washington DC, USA

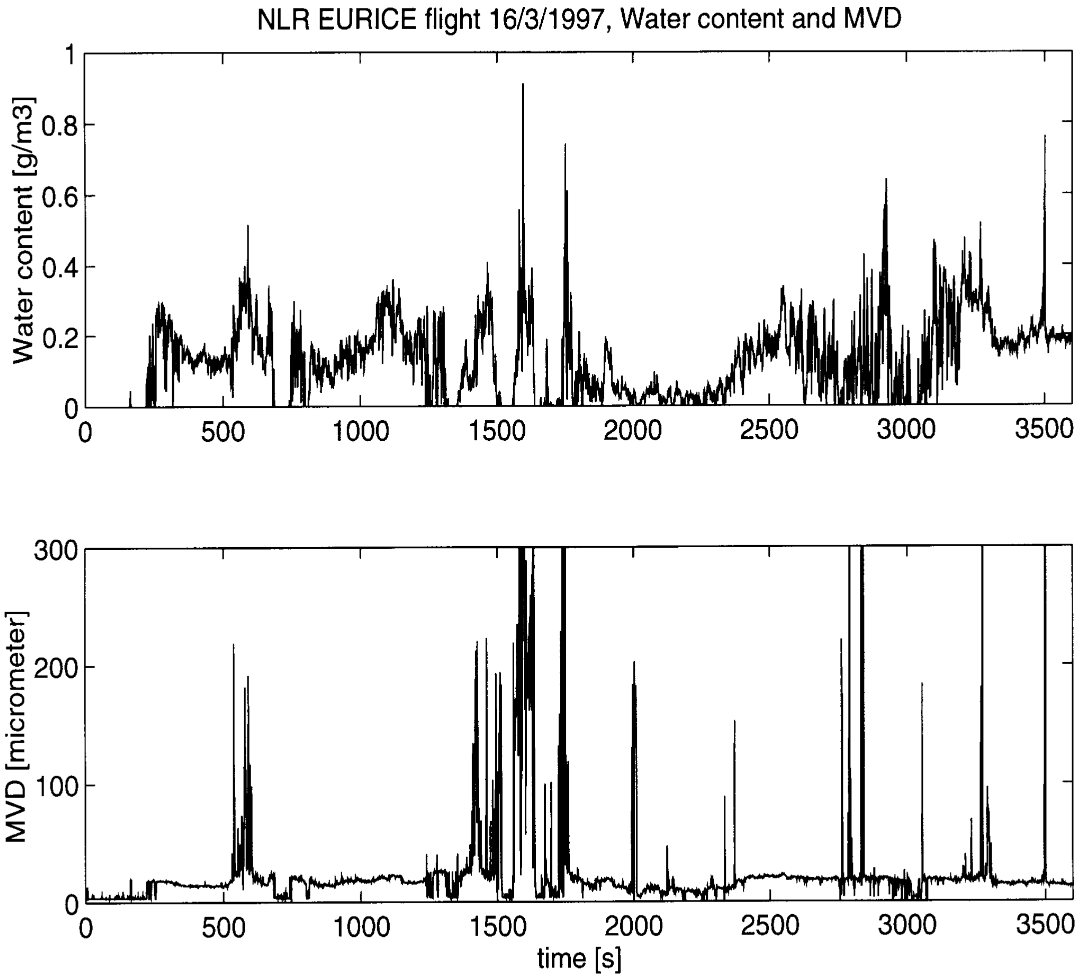

Fig. 4 Overview of the water content and MVD recorded in the first measurement flight on March 16, 1997. The values were derived from FSSP and OAP data. Measurements plotted were taken starting 50000 seconds after midnight (UTC).

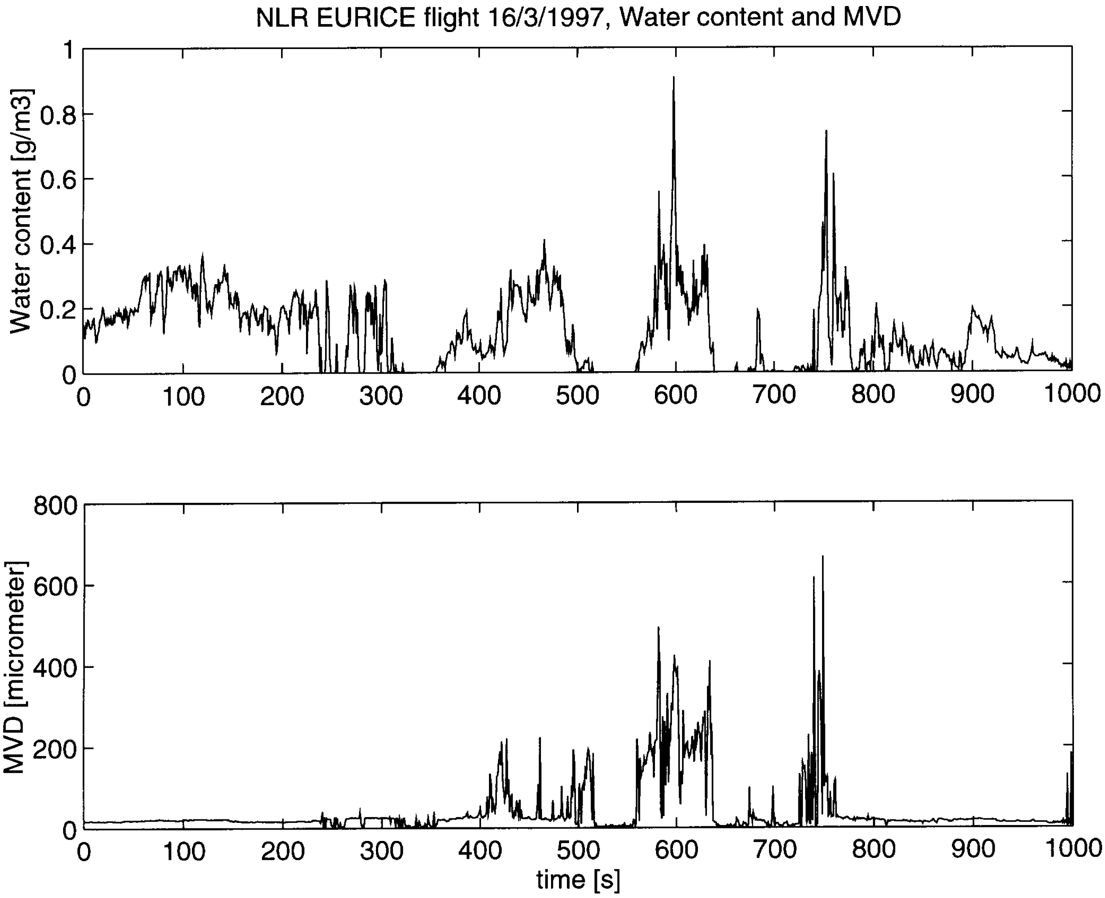

Fig. 5 The water content and the MVD time series derived from FSSP and OAP data. Measurements were taken on March 16, where this plot starts at 51000 seconds after midnight (UTC).

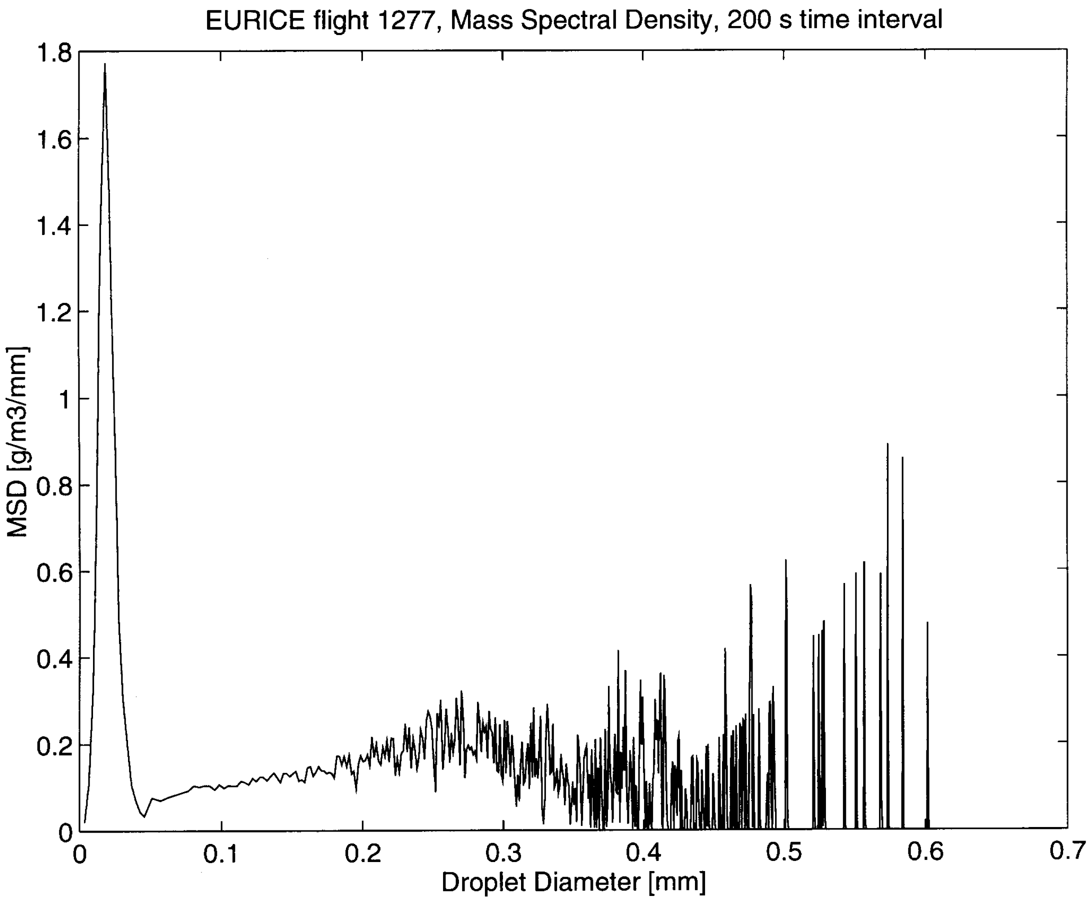

Fig. 6 Droplet mass density distribution for droplets measured in the flight on March 16 in the time interval 51500 to 51700 seconds after midnight. The maximum density of mass is for droplets of 19 micrometer, the MVD is 214 micrometer.

Fig. 7 Photograph of ice accretion on the wing of the research aircraft. Ice accretion is close to the leading edge of the wing on the de-icing boot.