PARAMETRIC STUDY OF ICE ACCRETION FORMATION ON A SWEPT WING AT SLD CONDITIONS

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OUTLINE

- Background
- Objectives
- Approach
- MVD Effect
- Temperature Effect
- Sweep Angle Effect
- Summary and Final Comments

BACKGROUND

- **Past Studies of ice accretion formation on swept wings were conducted at Appendix C conditions because of the complexity exhibited by ice shapes on swept wings**
  - **Needed to gain understanding of their formation in the simplest configuration and conditions before studying more complex situations**

- **The advances gained in understanding how ice accretions form on swept wings at Appendix C conditions lead us to begin extending the range of conditions to the SLD regime**

OBJECTIVES

- **To study the effect of sweep angle and temperature on the formation of ice accretions at SLD conditions**
  - **Effect on ice accretion shape**
  - **Effect on critical distance, d_{cr}**
- **To determine if the physics observed at Appendix C conditions is valid at SLD conditions**
  - **Effect of temperature and sweep angle on the critical distance**
  - **Formation of complete and incomplete scallops**
- **To begin developing a database of ice accretions and their tracings to be used for validation of 3D codes**

APPROACH

- **Experiment in the NASA Glenn Icing Research Tunnel using NACA 0012 swept wing tip**
- **Start from baseline condition: velocity 172.7mph (150kt), total temperature 25 ^{o}F, LWC 0.75 g/m^{3}, MVD 20 μm, ice accretion time 10 minutes**
- **Icing runs at drop sizes of 20, 110 and 200 μm**
- **Temperatures of 25, 20, 10 and 0 ^{o}F**
- **Sweep angles of 0^{o}, 15^{o}, 30^{o}, 45^{o}**
- **Obtain photographic data, tracings of ice shapes and castings**

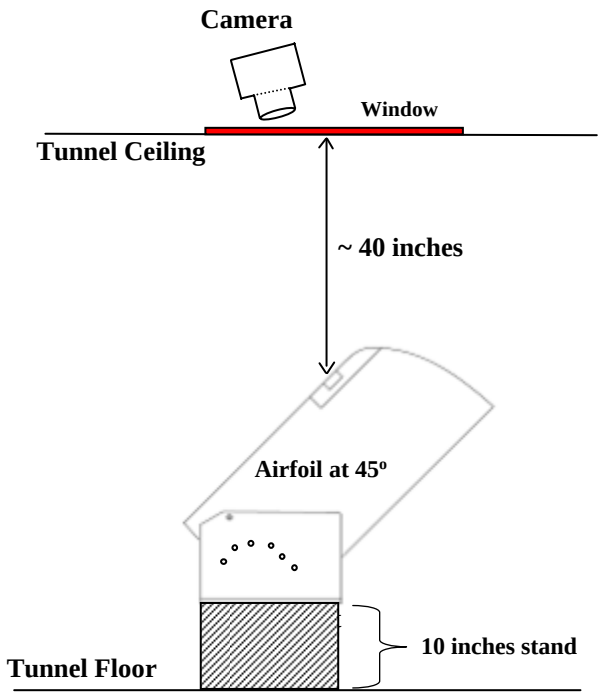
APPROACH

AIRFOIL

APPROACH

TUNNEL SET-UP

Configuration-A



APPROACH

TYPES OF PHOTOGRAPHIC DATA

- **Time sequence close-up photographic data**
  - **Taken at 2, 3, 5, 6 and/or 9 second intervals during each run**
  - **Main limitation: vibration of the airfoil and camera shutter speed**
- **Close-up photographic data at the end of each run**
  - **At the end of each run the close-up photographic data were taken in a pre-determined sequence and orientation of the camera with respect to the ice surface**
  - **For each run additional pictures were taken at a grazing angle to the surface of the ice. It was found that this approach allowed better observation of the 3D features on the ice surface.**

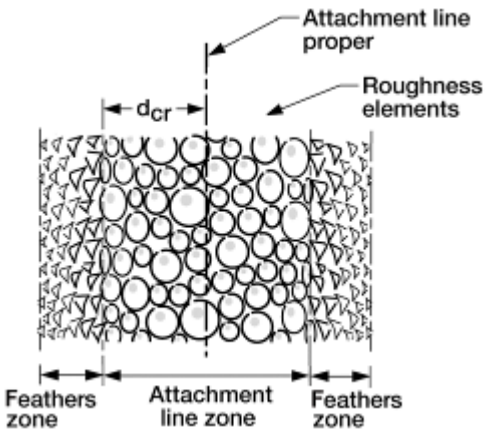
APPROACH

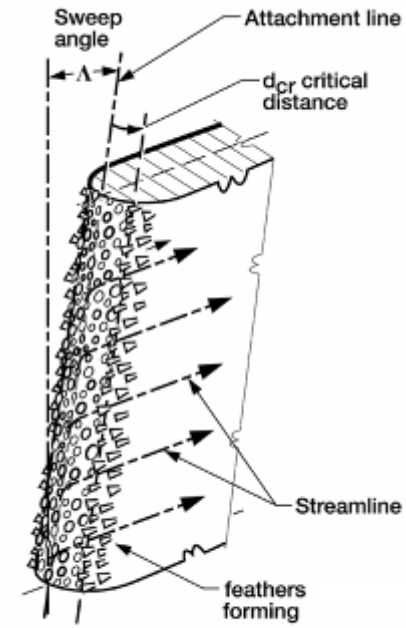
Baseline Case

$\Lambda = 45^{o}$, V = 150 kts (172.7 mph), $T_{total} = 25\ ^{o}F$, MVD = 20 μm, τ = 10 minutes

APPROACH

Conceptual Model & Critical Distance d_{cr}





Roughness elements at a given distance from the attachment line develop into feathers

MVD EFFECT AT SWEEP ANGLE OF 45^{o}

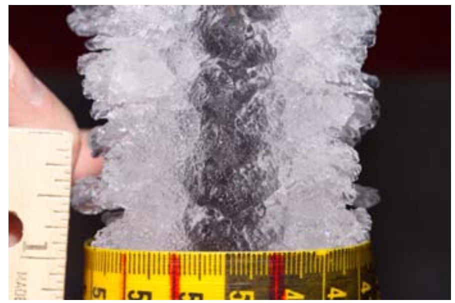
EFFECT OF INCREASING THE DROP SIZE AT Λ = 45º

Λ = 45º, V = 150 kt (172.7 mph), LWC = 0.75 g/m³

T_{total}= 25 ºF, MVD = 20 μm, τ = 10 minutes

Complete Scallop, d_{cr}= 0 mm

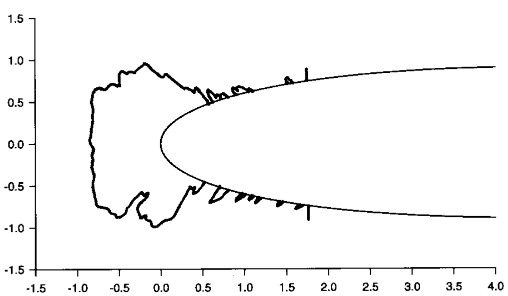
MVD = 110μm

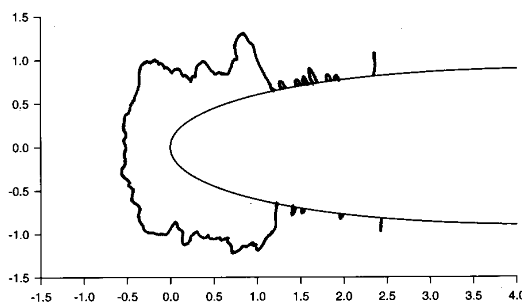


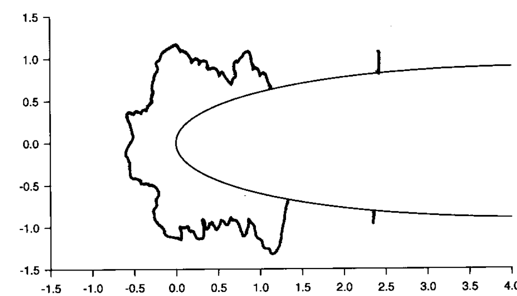
Incomplete Scallop, d_{cr}= 9 mm

MVD = 200μm

Incomplete Scallop, d_{cr}= 13 mm







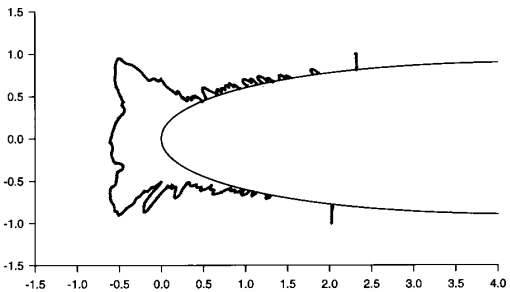
MVD EFFECT AT SWEEP ANGLE OF 30^{o}

EFFECT OF INCREASING THE DROP SIZE AT $\Lambda = 30^o$

$\Lambda = 30^o$, V = 150 kt (172.7 mph), LWC = 0.75 g/m^3

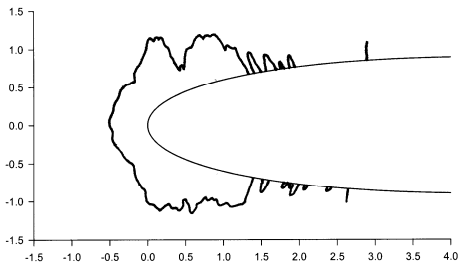
T_{total}= 25 ^{o}F, MVD = 20 μm, τ = 10 minutes

Incomplete Scallop, d_{cr}= 7 mm



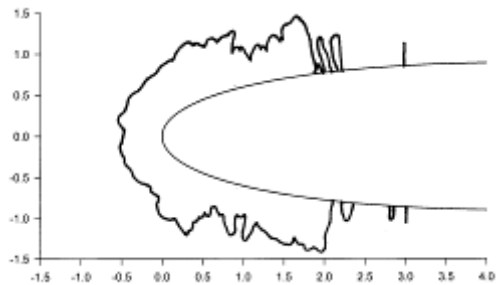
MVD = 110μm

d_{cr}= 14 mm



MVD = 200μm

d_{cr}= 16 mm



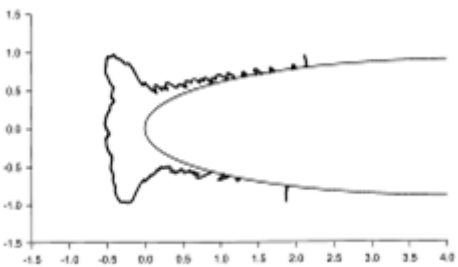
MVD EFFECT AT SWEEP ANGLE OF 15^{o}

EFFECT OF INCREASING THE DROP SIZE AT $\Lambda = 15^o$

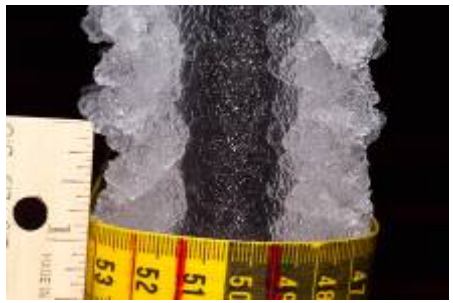
$\Lambda = 15^o$, V = 150 kt (172.7 mph), LWC = 0.75 g/m^3

T_{total}= 25 ^{o}F, MVD = 20 μm, τ = 10 minutes

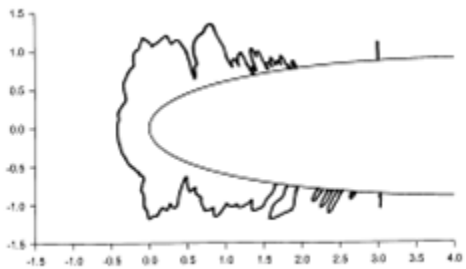
No-scallop, d_{cr}= 9 mm



MVD = 110μm

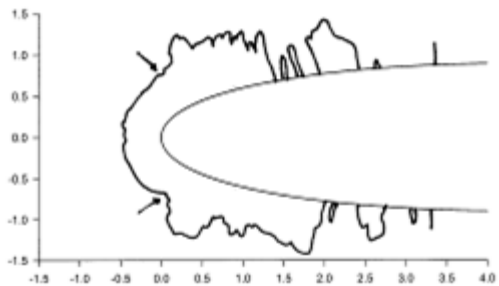


No-scallop, d_{cr}= 10 mm



MVD = 200μm

No-scallop, d_{cr}= 16 mm



TEMPERATURE EFFECT AT

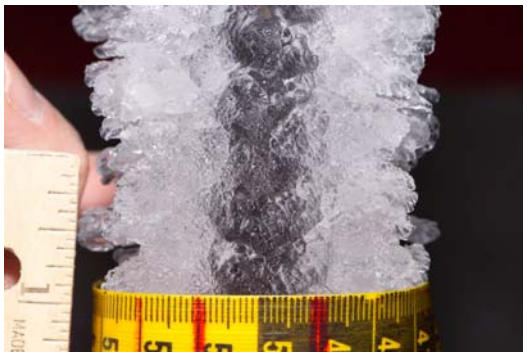
$\Lambda = 45^{O}$ AND MVD = 110μm

EFFECT OF DECREASING THE TEMPERATURE

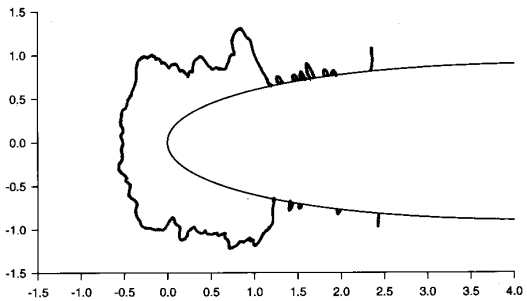
$\Lambda = 45^o$, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

T_{total}= 25 ^{o}F, MVD = 110 μm, τ = 10 minutes

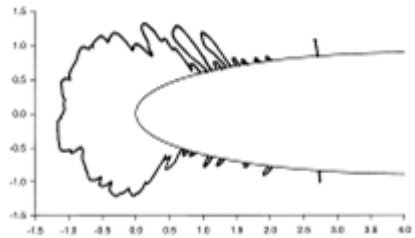
T_{total} = 20 ^{o}F



Incomplete Scallop, d_{cr}= 9 mm



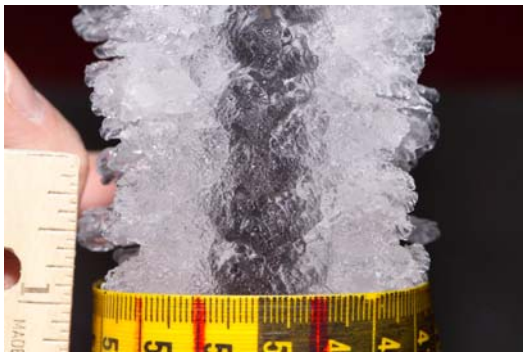
Complete Scallop, d_{cr}= 0 mm



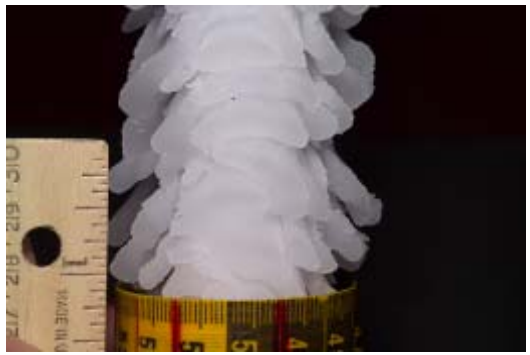
EFFECT OF DECREASING THE TEMPERATURE

$\Lambda = 45^o$, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

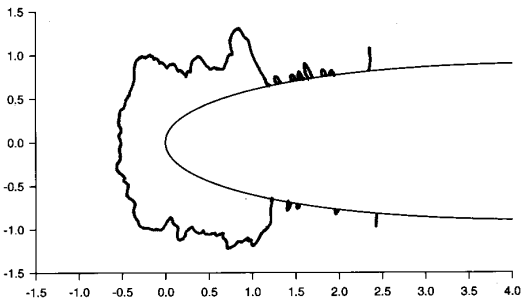
T_{total}= 25 ^{o}F, MVD = 110 μm , τ = 10 minutes



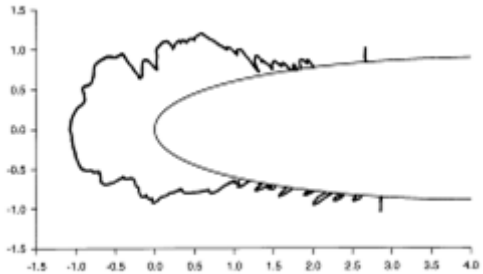
T_{total} = 10 ^{o}F



Incomplete Scallop, d_{cr}= 9 mm



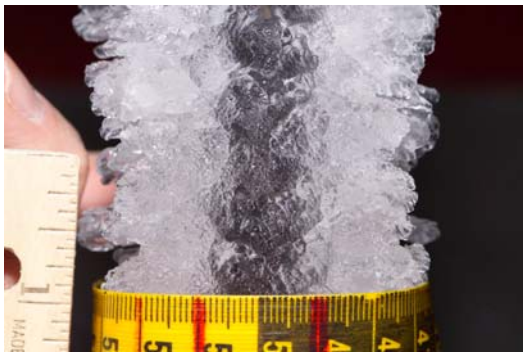
Complete Scallop, d_{cr}= 0 mm



EFFECT OF DECREASING THE TEMPERATURE

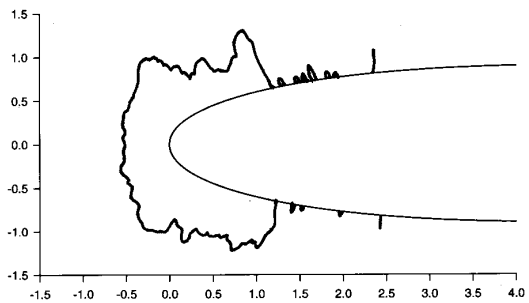
$\Lambda = 45^o$, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

T_{total}= 25 ^{o}F, MVD = 110 μm , τ = 10 minutes

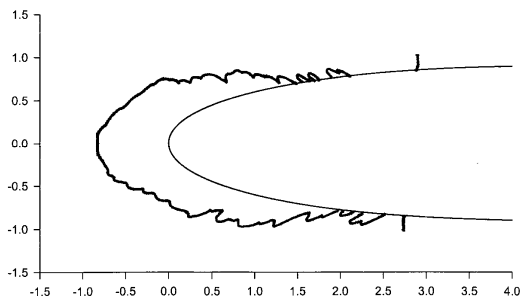


T_{total} = 0 ^{o}F

Incomplete Scallop, d_{cr}= 9 mm



Rime Ice Accretion



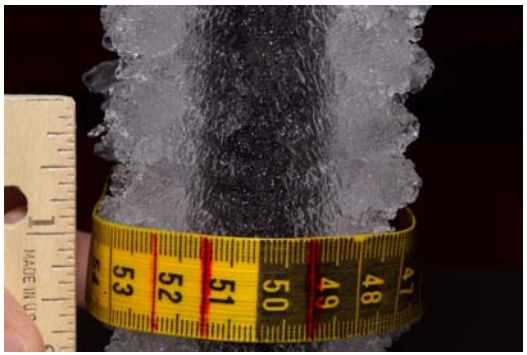
TEMPERATURE EFFECT AT

$\Lambda = 30^{O}$ AND MVD = 110μm

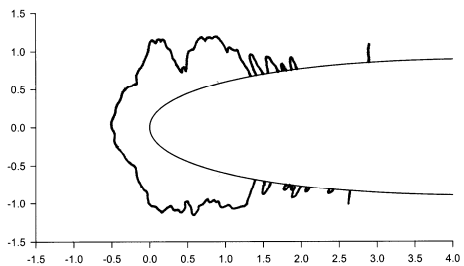
EFFECT OF DECREASING THE TEMPERATURE AT MVD=110 μm

Λ = 30°, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

T_{total}= 25 °F, MVD = 110 μm , τ = 10 minutes

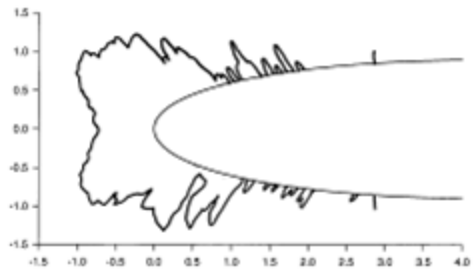


d_{cr}= 14 mm



T_{total} = 20 °F

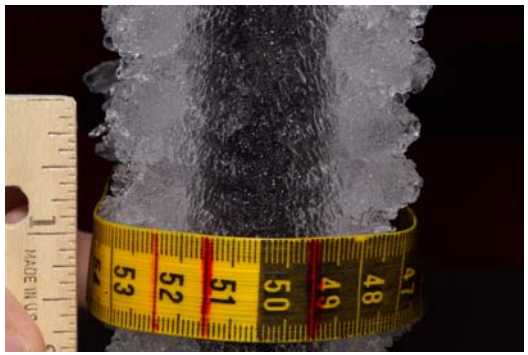
Incomplete Scallop, d_{cr}= 5 mm



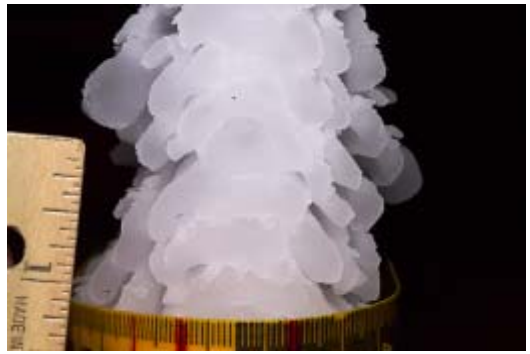
EFFECT OF DECREASING THE TEMPERATURE AT MVD=110 μm

Λ = 30°, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

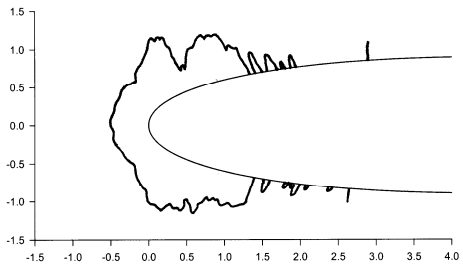
T_{total}= 25 °F, MVD = 110 μm , τ = 10 minutes



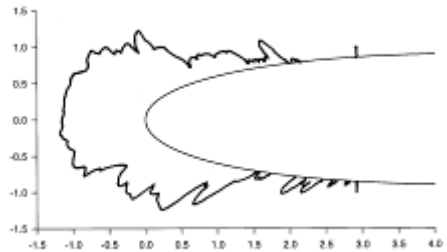
T_{total} = 10 °F



d_{cr}= 14 mm



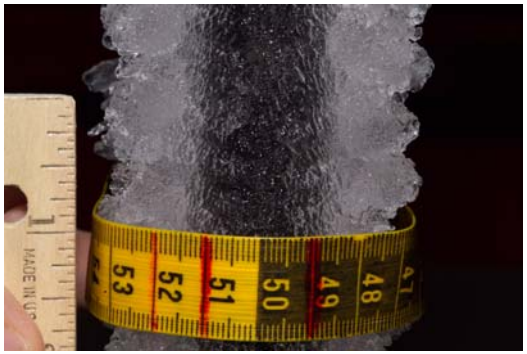
Complete Scallop, d_{cr}= 0 mm



EFFECT OF DECREASING THE TEMPERATURE AT MVD=110 μm

Λ = 30°, V = 150 kt (172.7 mph), LWC = 0.66 g/m^3

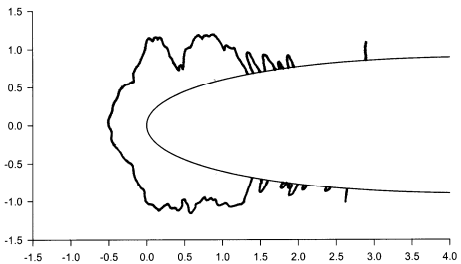
T_{total}= 25 °F, MVD = 110 μm , τ = 10 minutes

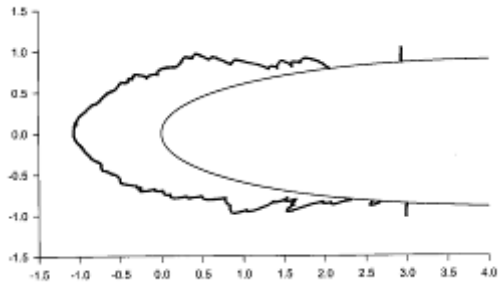


T_{total} = 0 °F

d_{cr}= 14 mm

Rime Ice Accretion



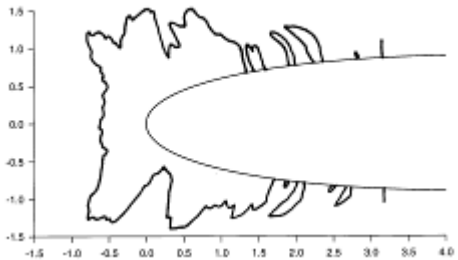
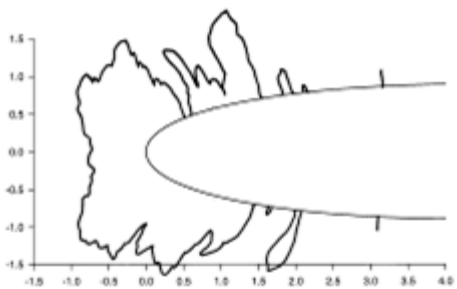
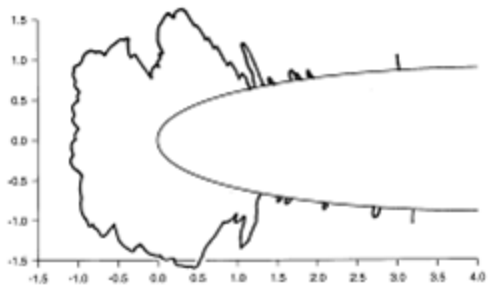


SWEEP ANGLE EFFECT AT

T_{total} = 20 ^{O}F AND MVD = 200μm

SWEEP ANGLE EFFECT

V = 150 kt (172.7 mph), LWC = 0.75 g/m^3, T_{total}= 20 ^{o}F, MVD = 200 μm, τ = 10 minutes

Λ = 15^o	Λ = 30^o	Λ = 45^o
		
No-Scallop, d_{cr}= 5 mm	**Incomplete Scallop, d_{cr}= 5 mm**	**Complete scallop, d_{cr}= 0 mm**
		

SUMMARY

- Increasing the MVD from 20 to 110 and 200 μm increased the critical distance at all sweep angles with the resulting effect of changing the ice accretion formation and shape
- At the SLD conditions (110 and 200 μm) and large sweep angles (45° and 30°), the effect of temperature was very strong. The ice accretion changed from an incomplete scallop at total temperatures of 25 °F and 20 °F to a complete scallop at a temperature of 10 °F. The resulting complete scallop was made of mixed-rime ice.
- The time-sequence photography did not indicate different physics of formation at SLD conditions compared to past observations at Appendix C conditions
- Castings of the ice accretions were obtained and are being used to initiate the development of a database