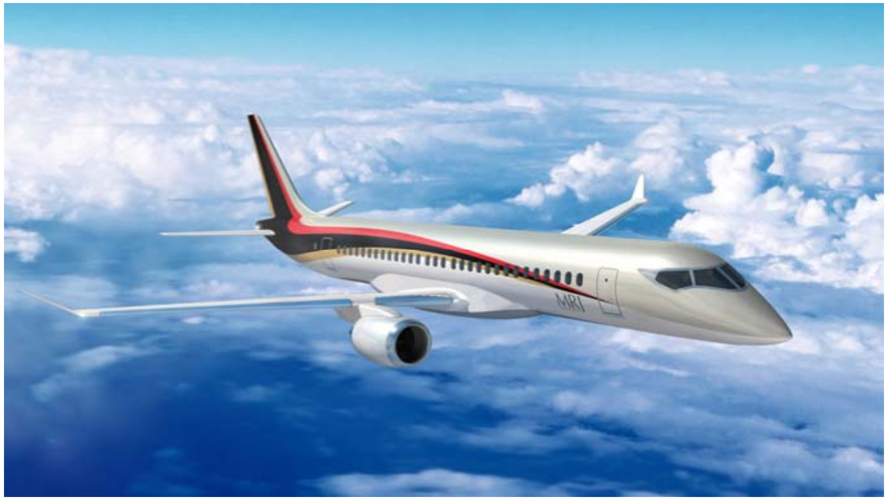
Validation of FENSAP-ICE at MHI



September, 2007

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07ICE-148

Table of Contents

1. Background

1. Conceptual Study of 70-90 Passenger Class Regional Jet (Mitsubishi Regional Jet : MRJ) has been done by MHI under the partial support of New Energy Development Organization of the Japanese Government.
2. Icing is more critical issue in this class of aircraft than larger aircraft.
   - Relatively large ice accreted
   - Severe penalty on performance from icing

1. Background (cont.)

3. Icing calculation is necessary for conceptual study.
    - Determine protection area
4. This material presents the results of validation works done by MHI for the application of conceptual design of MRJ based on published data.

2. Validation of Droplet Impingement Analysis

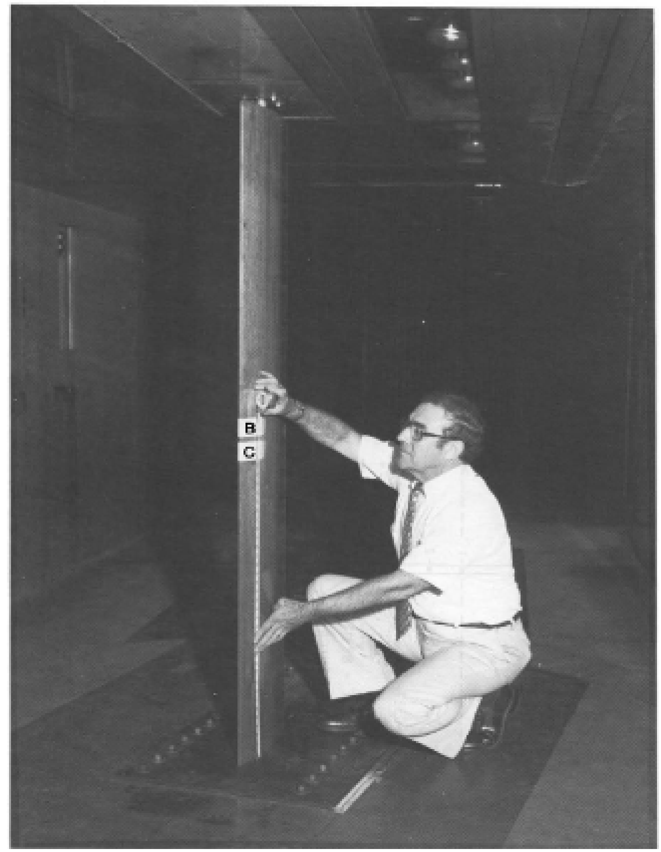
2. Validation of Droplet Impingement Analysis

2. 1 Experimental Data

Literature: Papadakis, M., et.al.
An experimental method for measuring water droplet impingement efficiency on two- and three-dimensional bodies, NASA CR 4257, 1989.

Model: 2D NACA$65_2$015 airfoil (0.33m chord)
2D MS(1)-0317 airfoil (0.33m chord)

Wind Tunnel: NASA Glenn Research Center's Icing Research Tunnel



2. Validation of Droplet Impingement Analysis

2. 2 Conditions

- Mach No. : 0.25 (81 m/sec)
- Reynolds No. : 1.8 million
- AoA : 0, 8 deg.
- MVD: 16μ, 20μ (distribution is shown in the table below)
- Turbulent Model : Spalart and Allmaras Model

Droplet Volume Diameter Distribution (MVD=16.45ƒÊm)

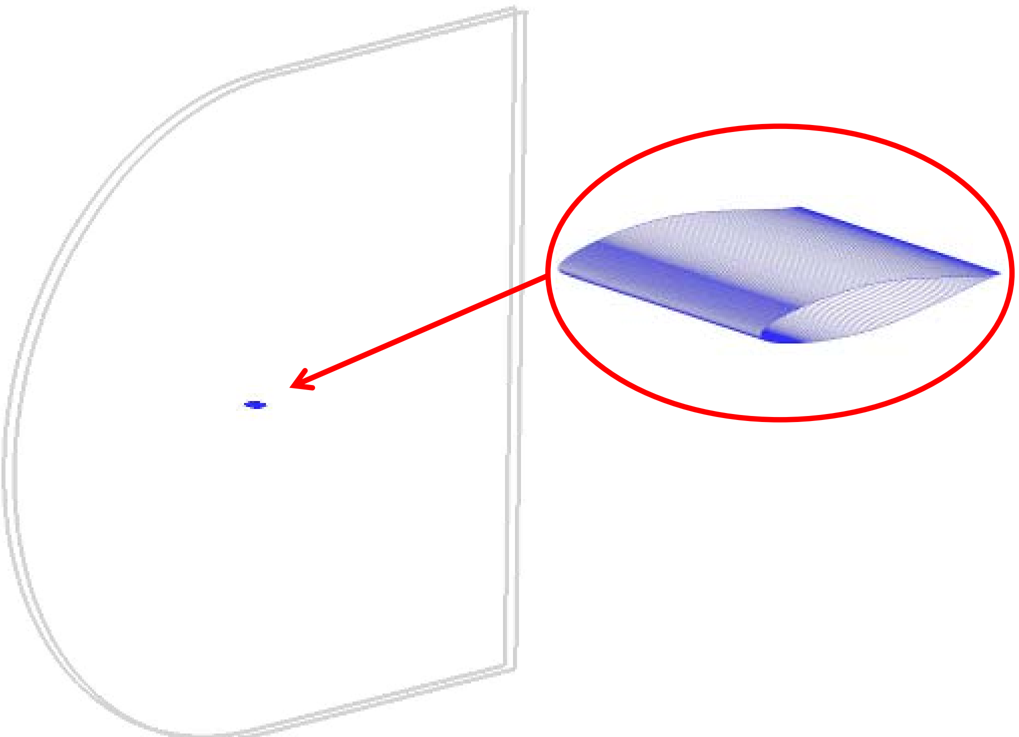
Proportion [%]	5	10	20	30	20	10	5
MVD [ƒÊm]	5.20	8.19	11.30	16.45	22.60	32.27	46.53

Droplet Volume Diameter Distribution (MVD=20.36ƒÊm)

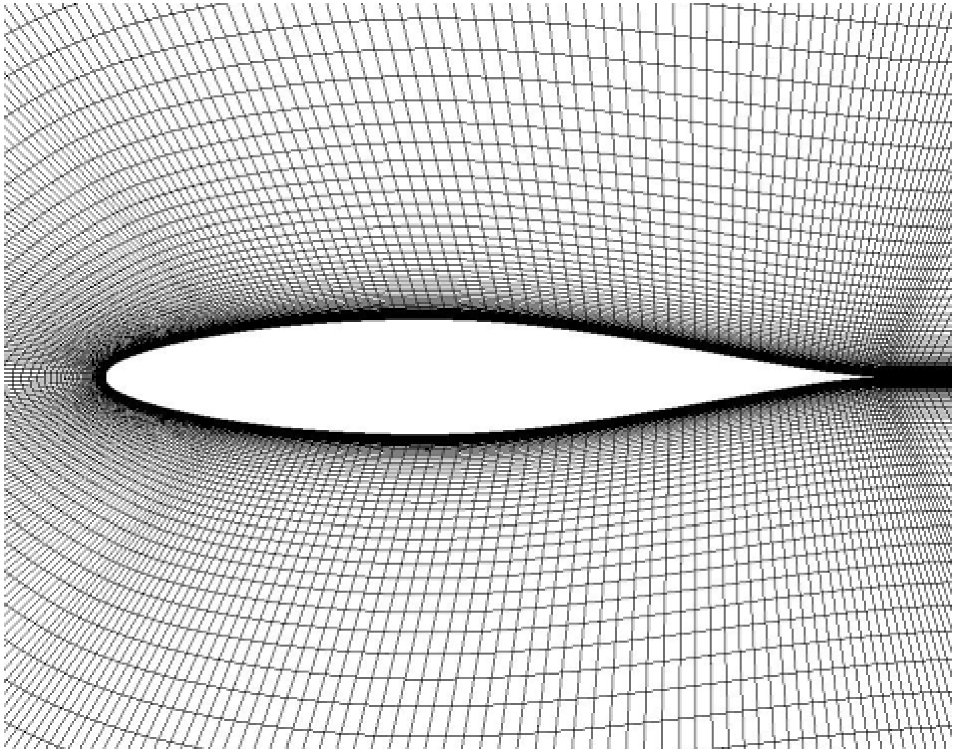
Proportion [%]	5	10	20	30	20	10	5
MVD [ƒÊm]	5.64	9.08	13.47	20.36	32.30	46.71	66.26

2. Validation of Droplet Impingement Analysis

2. 3 Grid NACA65$_2$015



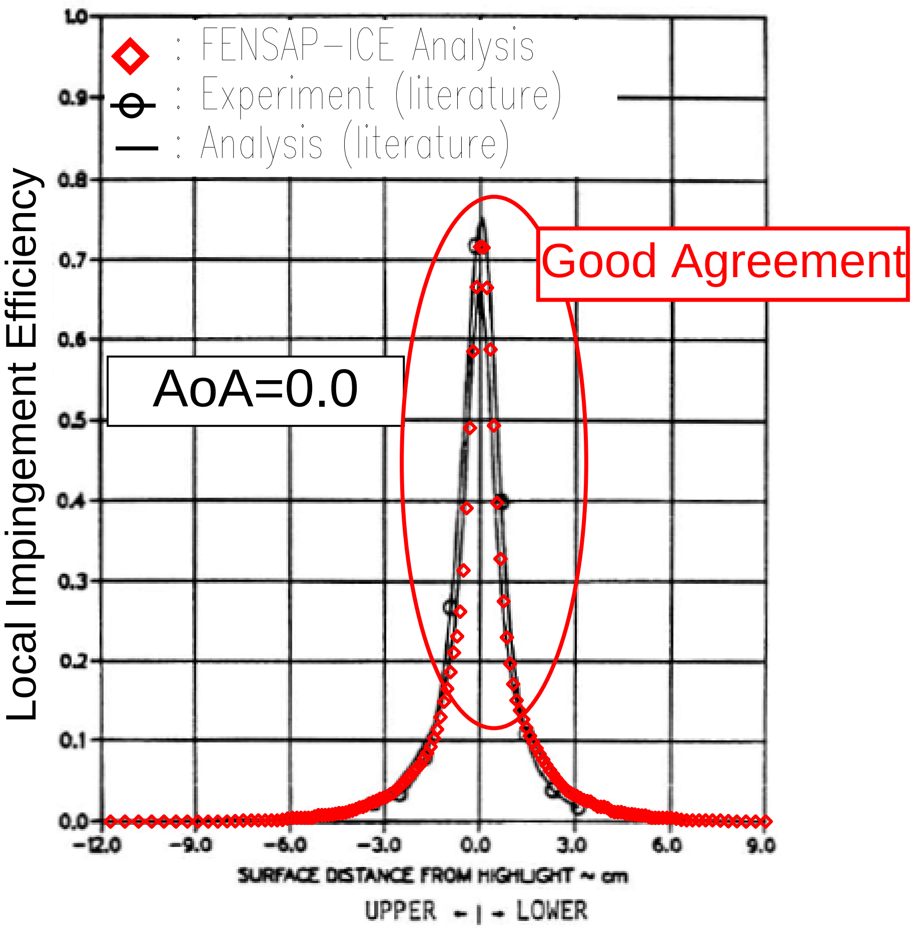
Number of z direction grid is 1 to simulate 2D field.

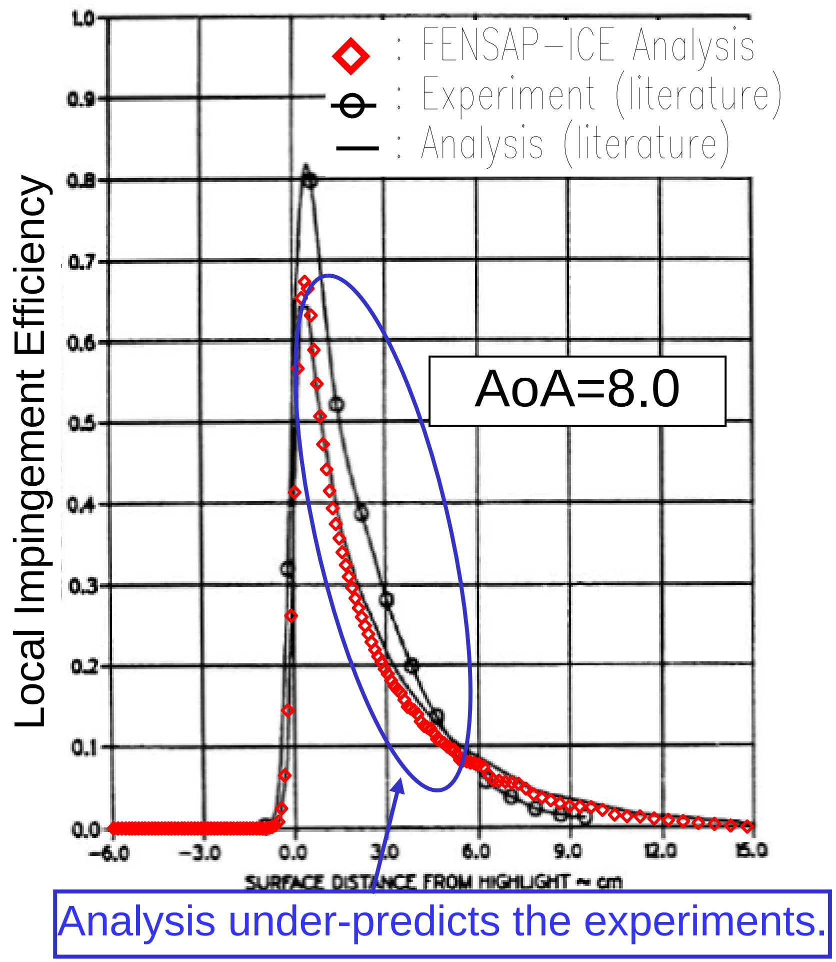


Grid type : structured grid
Number of grids : 26 thousands

2. Validation of Droplet Impingement Analysis

2. 4 Result NACA65$_2$015 (MVD: 16μ)

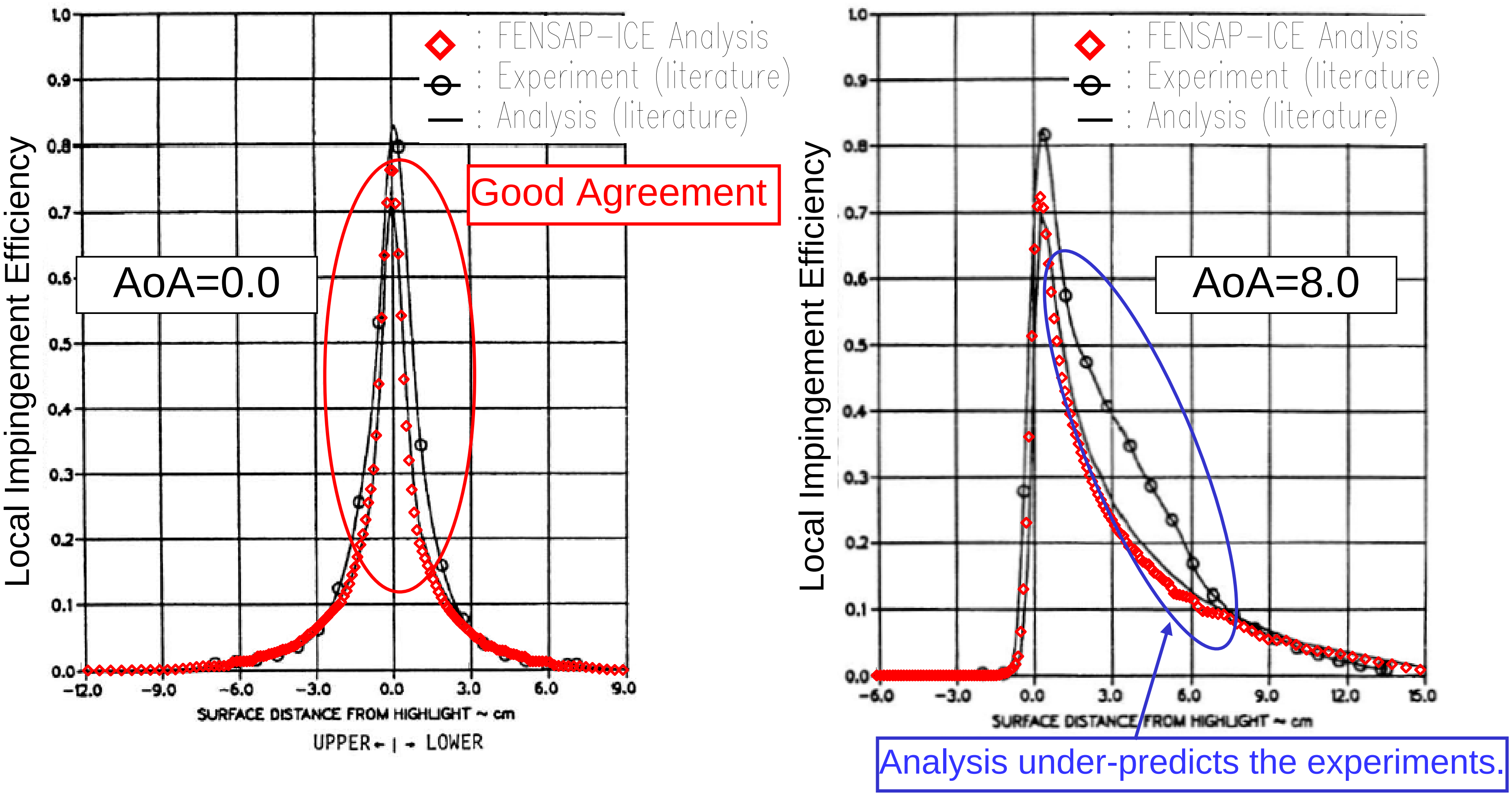




Local Impingement Efficiency

2. Validation of Droplet Impingement Analysis

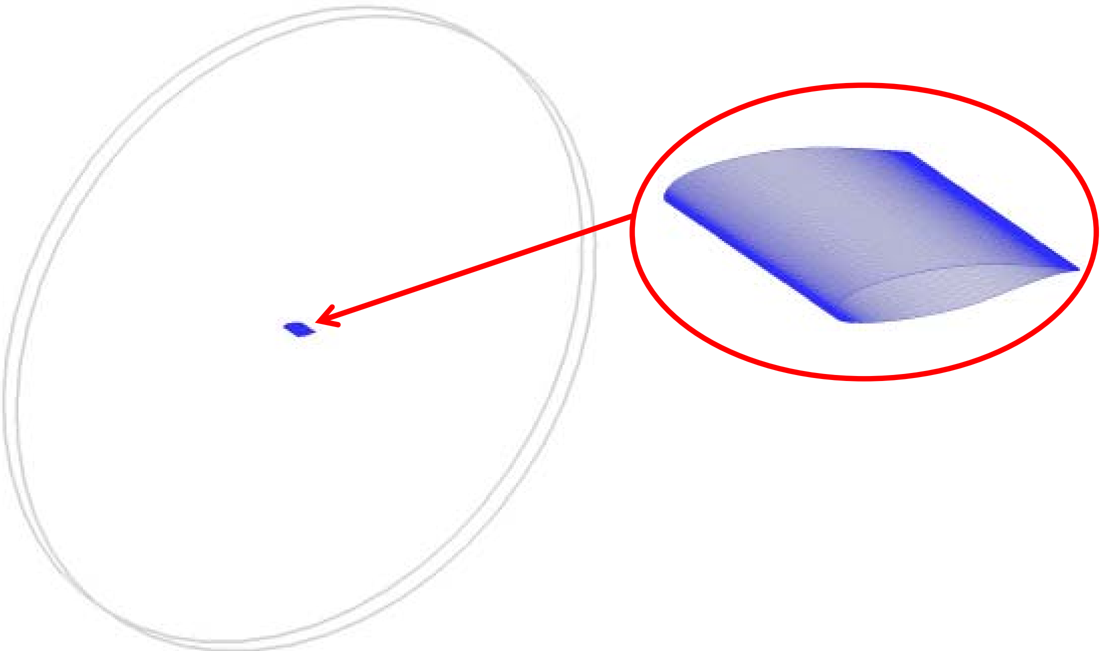
2. 4 Result NACA65$_2$015 (MVD:20μ)

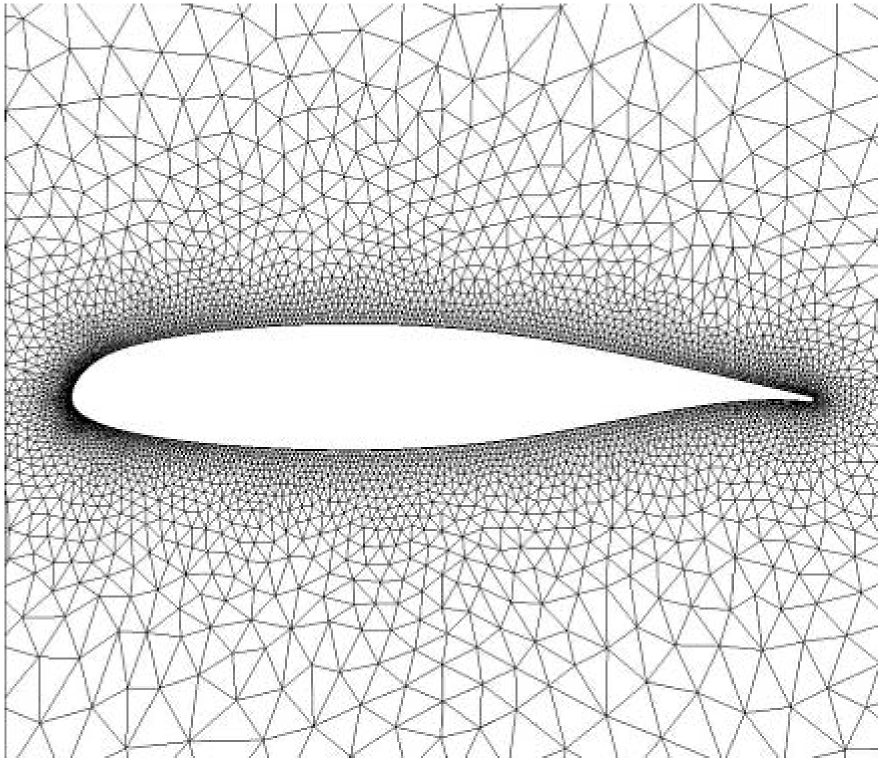


Local Impingement Efficiency

2. Validation of Droplet Impingement Analysis

2. 3 Grid MS(1)-0317



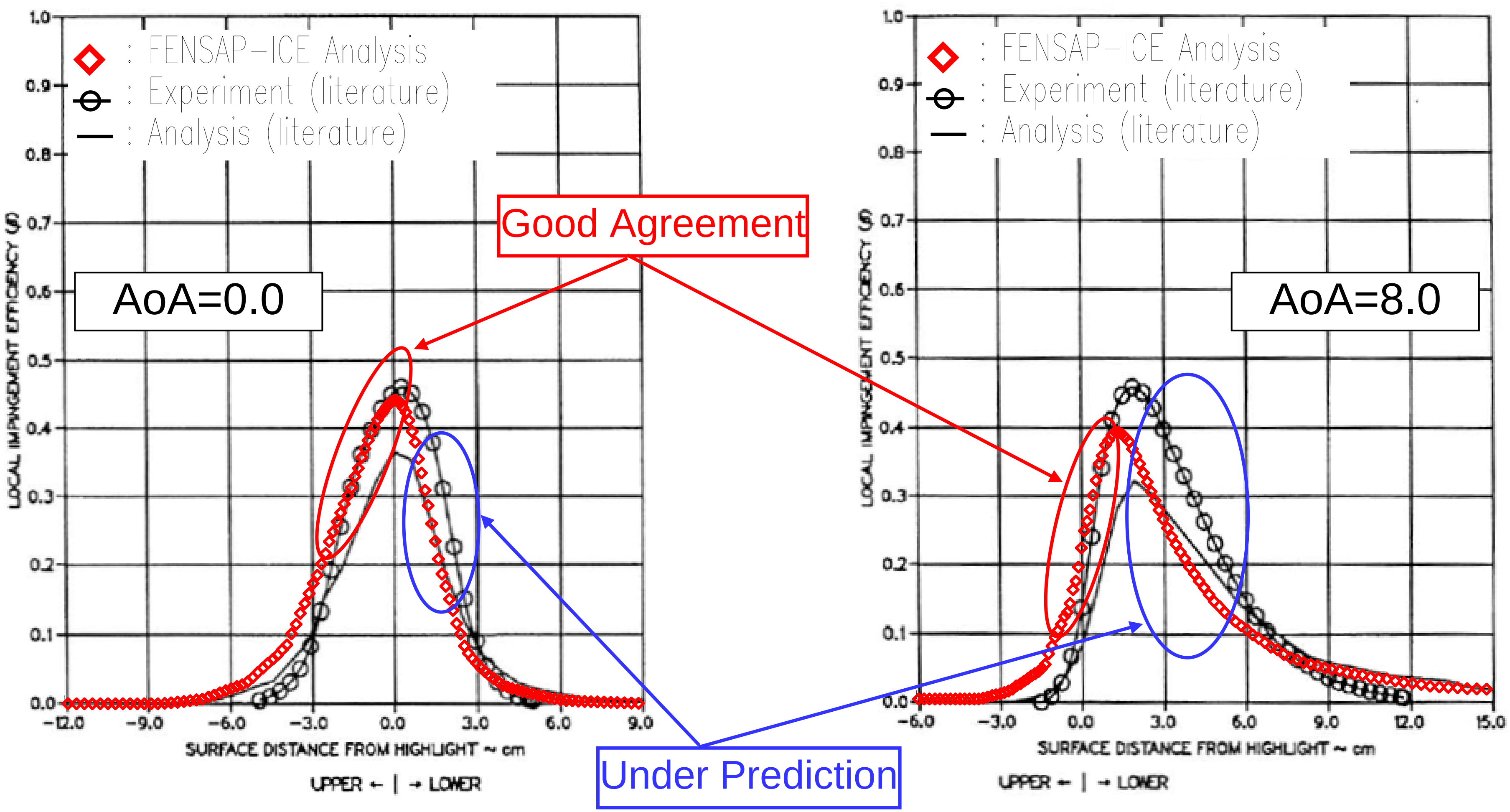


Number of z direction grid is 1 to simulate 2D field.

Grid type : unstructured grid
Number of grids : 21 thousands

2. Validation of Droplet Impingement Analysis

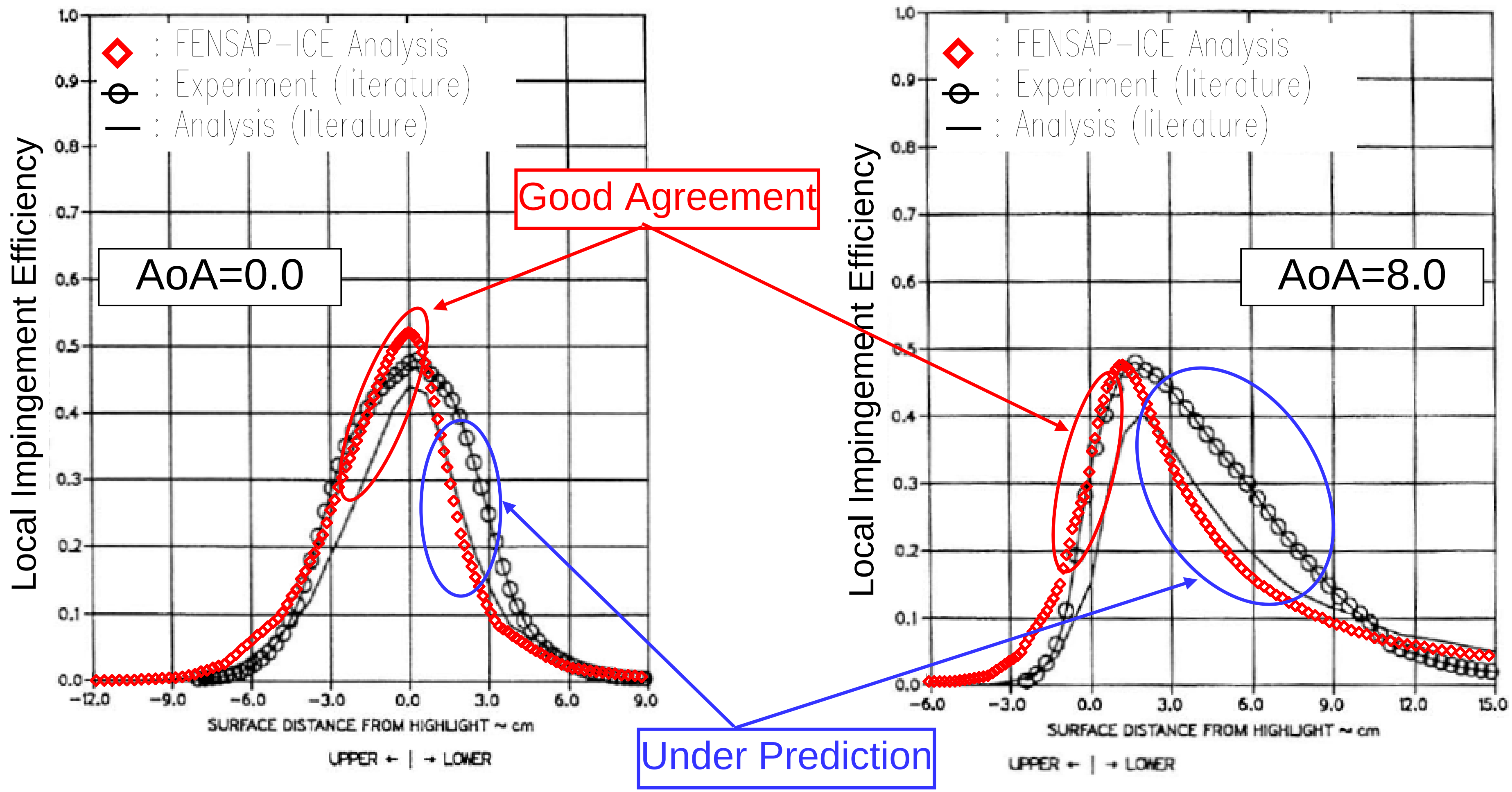
2. 4 Result MS(1)-0317 (MVD: 16μ)



Local Impingement Efficiency

2. Validation of Droplet Impingement Analysis

2. 4 Result MS(1)-0317 (MVD:20μ)



Local Impingement Efficiency

2. Validation of Droplet Impingement Analysis

2.5 Summary

- The results of local impingement efficiency on two-dimensional airfoil are found to be
  - ✓same tendency with analysis from literature and FENSAP.
  - ✓good agreement near the peak.
  - ✓better agreement in upper surface.
  - ✓lower in analyses than in experiments on lower surface.

- It is necessary to evaluate how much the difference in droplet impingement analysis affects the ice shape.

- The validation in three dimensional analysis is planned to be conducted as a next step study.

3. Validation of Ice Shape Analysis

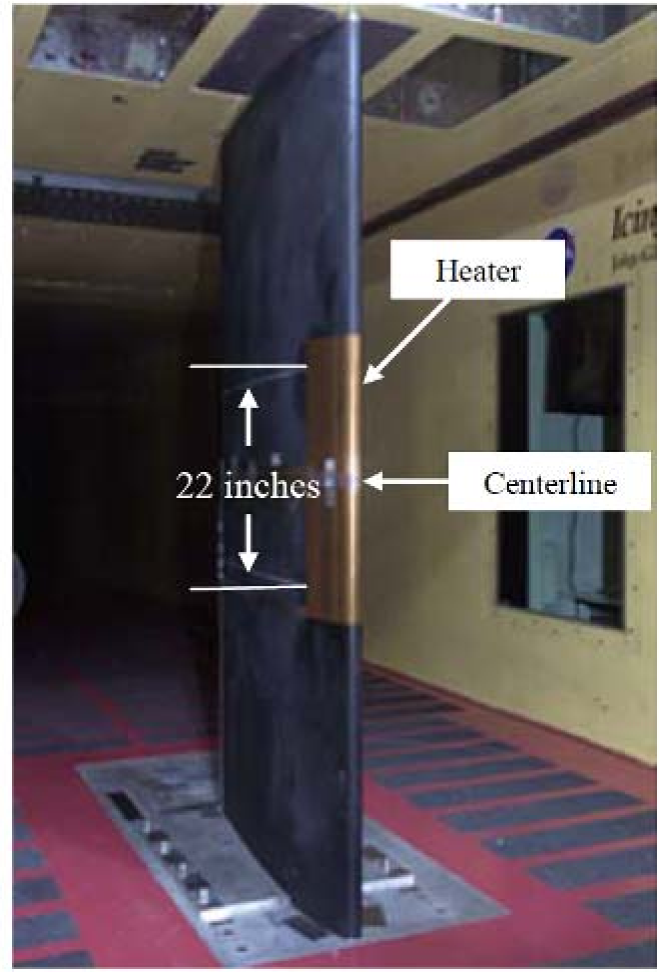
3. Validation of Ice Shape Analysis

3. 1 Experimental Data

Literature: Miller, D. R. et.al
NASA TM 2005-213562
Preliminary Investigation of Ice Shape Sensitivity to Parameter Variations

Model: 2D NACA0012 airfoil
(Chord Length: 36 inches)

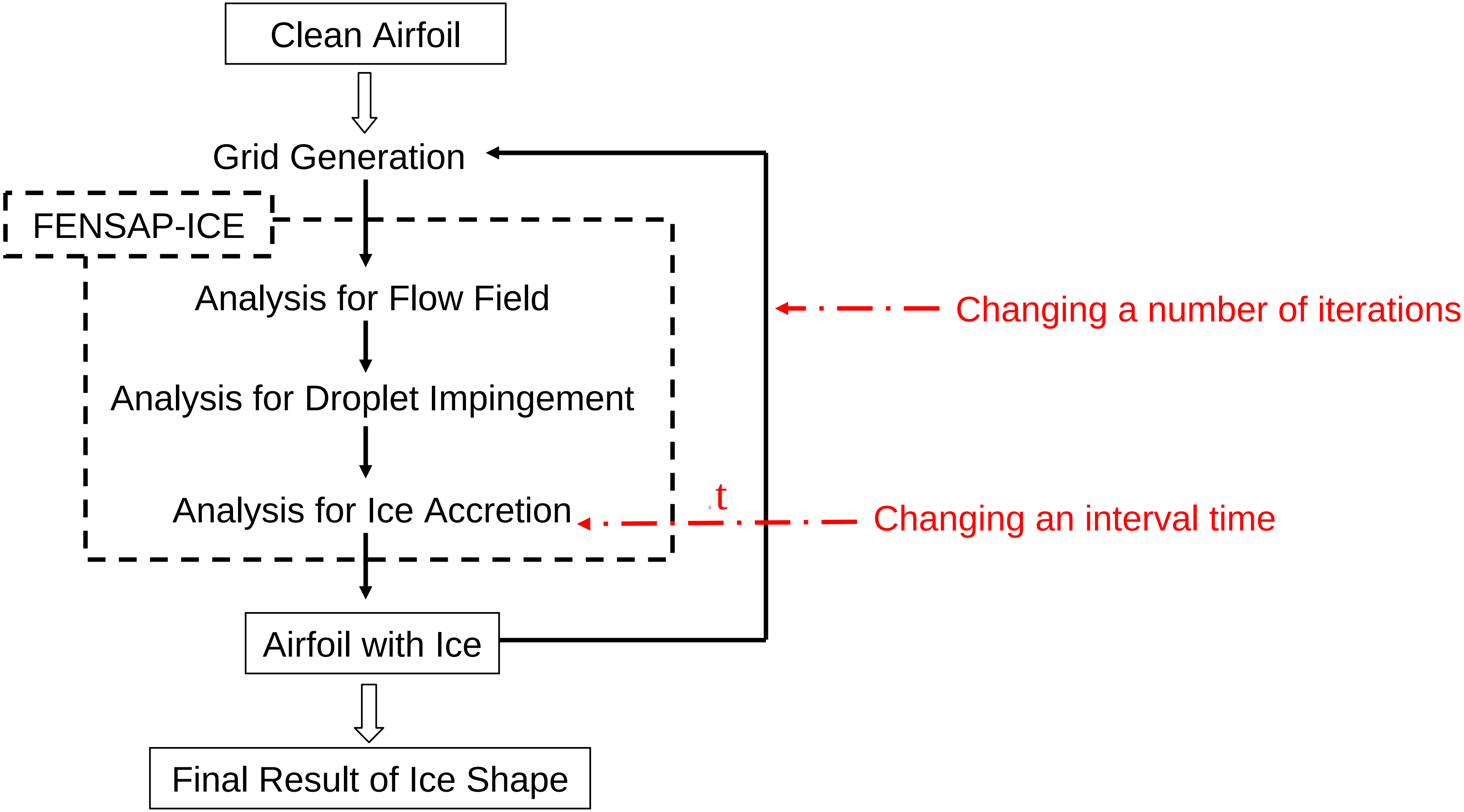
Facility: NASA Glenn Research Center's Icing Research Tunnel



Test Model

3. Validation of Ice Shape Analysis

3. 2 Computation Procedure



Analysis Flow Chart

3. Validation of Ice Shape Analysis

3. 2 Conditions

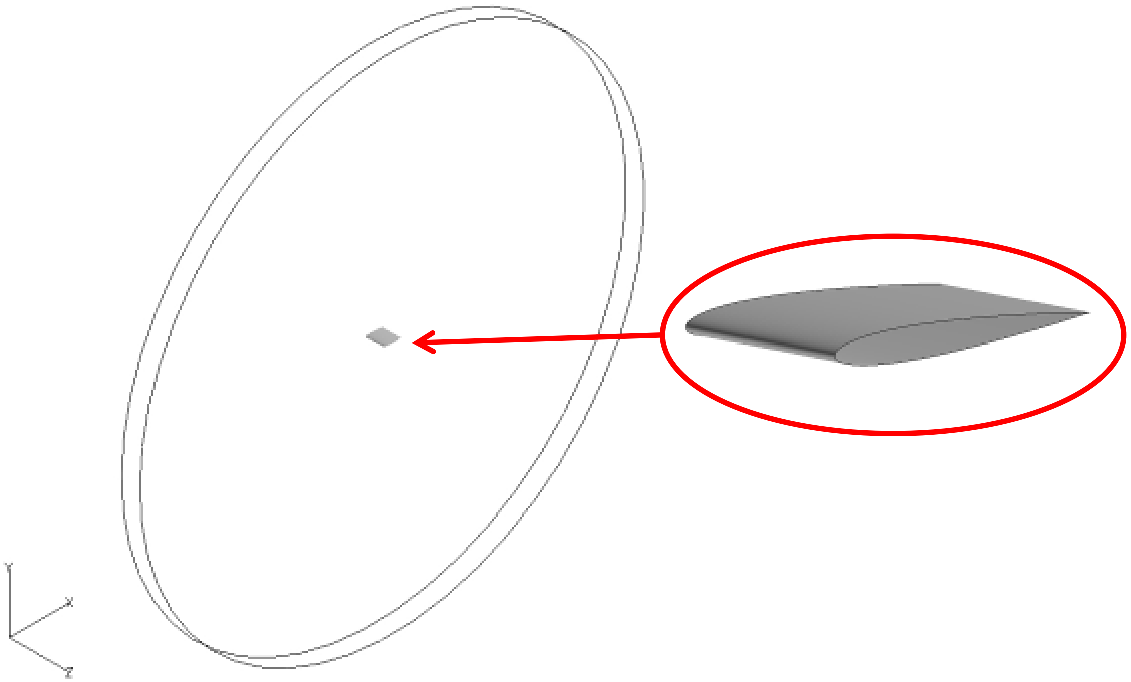
- Mach No. : 0.28 (93 m/sec)
- Reynolds No. : 2 million
- AoA : 2.5 deg.
- MVD: 80μ
- LWC: 0.6 g/m^3
- Total Time: 816sec (14min.)

Case	Iteration Number [-]	Interval Time (Total Time)					
		1st	2nd	3rd	4th	5th	6th
		[s]					
1	1	816 (816)					
2	6	136 (136)	136 (272)	136 (408)	136 (544)	136 (680)	136 (816)
3	6	60 (60)	60 (120)	60 (180)	60 (240)	60 (300)	516 (816)
4	3	120 (120)	300 (420)	396 (816)			
5	2	240 (240)	576 (816)				
6	2	420 (420)	396 (816)				

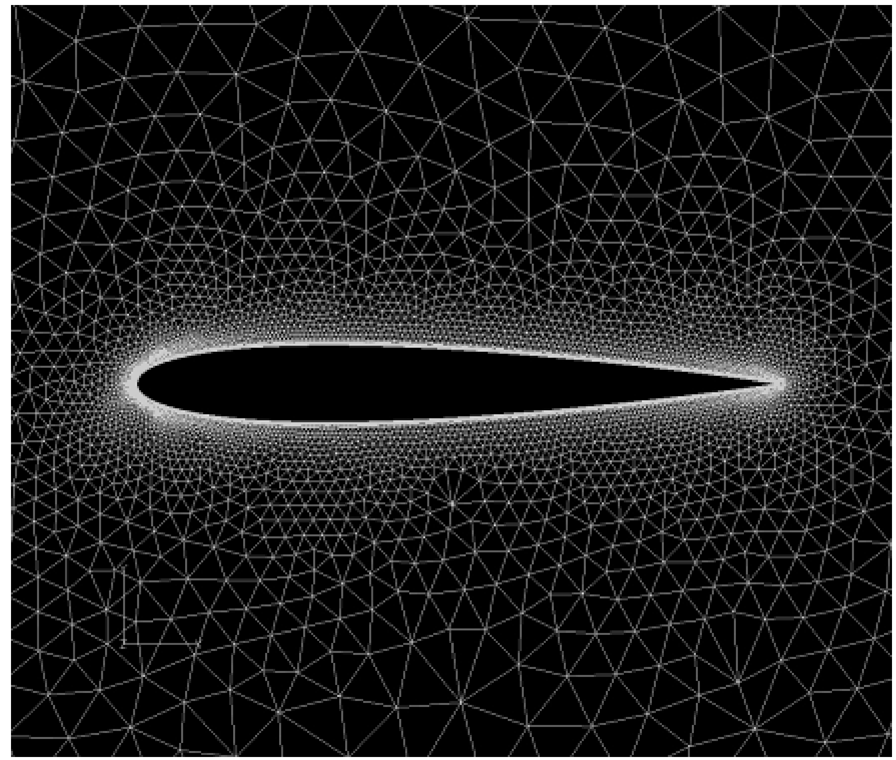
Variable parameters

3. Validation of Ice Shape Analysis

3. 3 Grid



Number of z direction grid is 1 to simulate 2D field.

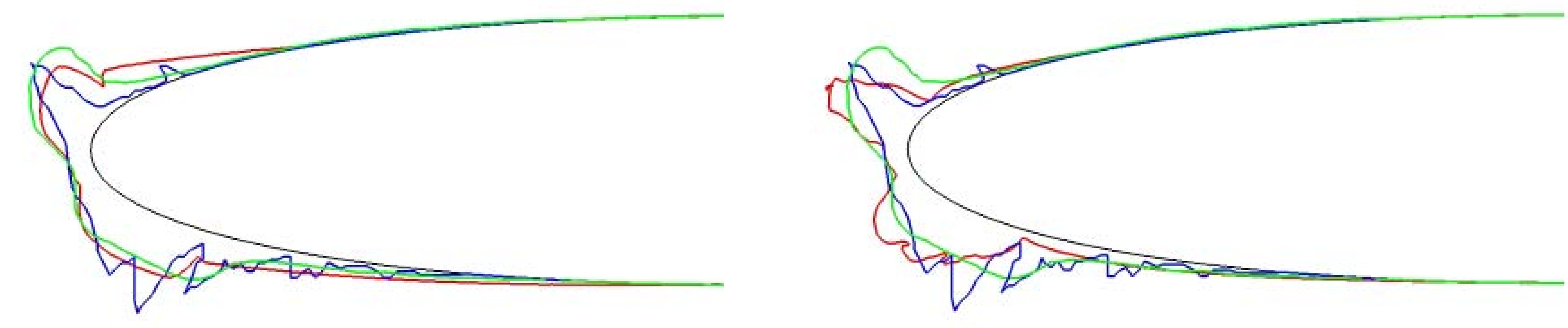


Grid type : unstructured grid
Number of grids : 19 thousands

Fig4.3-1 Grid

3. Validation of Ice Shape Analysis

3. 4 Results



red : FENSAP analysis
blue : Icing wind tunnel test
green : LEWICE analysis

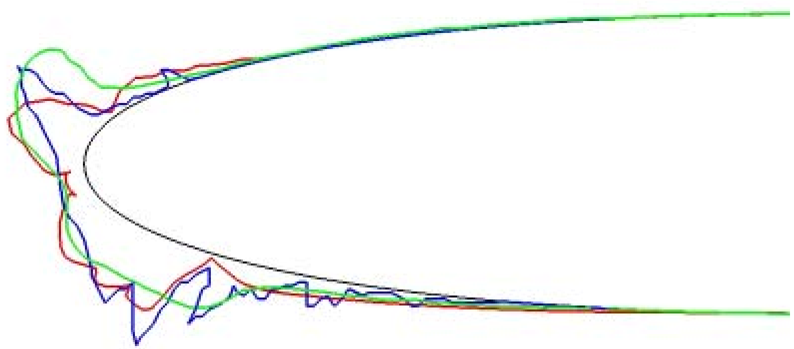
Case1
(One Shot Calculation)

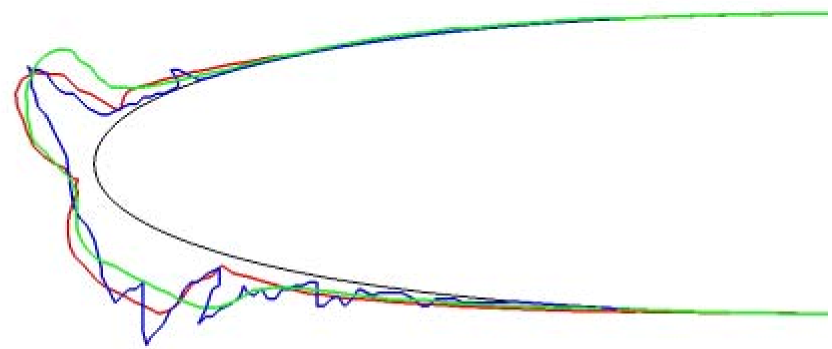
Case2
(Six Shots: Equally divided)

Fig4.4-1(1/3) Ice Shape

3. Validation of Ice Shape Analysis

3. 4 Results





red : FENSAP analysis
blue : Icing wind tunnel test
green : LEWICE analysis

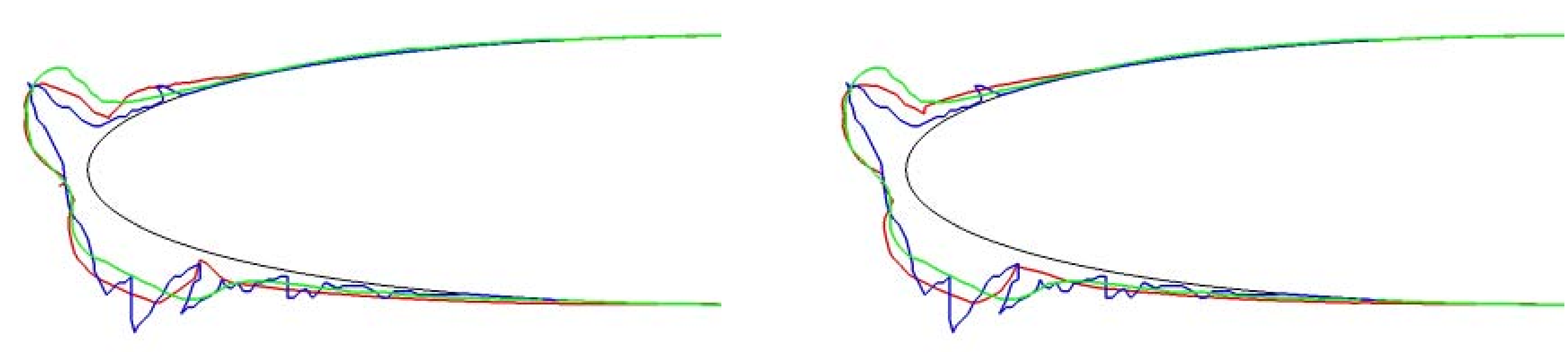
Case3
(Six Shots: Short interval at the beginning)

Case4
(Three Shots: Short interval at the beginning)

Fig4.4-1(2/3) Ice Shape

3. Validation of Ice Shape Analysis

3. 4 Results



red : FENSAP analysis
blue : Icing wind tunnel test
green : LEWICE analysis

Case5
(Two Shots: 240sec, 576sec)

Case6
(Two Shots: 420sec, 396sec)

Fig4.4-1(3/3) Ice Shape

3. Validation of Ice Shape Analysis

3. 5 Summary

- Compared to the other cases, ice shapes from case 5 & 6 (2 shots calculation) are close to ice shapes from icing wind tunnel test and LEWICE, especially in horn height and angle at upper surface.

- The height at lower surface ice from FENSAP-ICE and LEWICE is lower than that from experiments.

⇩

- The most practical analysis techniques in this study are shown to be case 5 & 6 (2 shots calculation).

4. Application to Horizontal Stabilizer

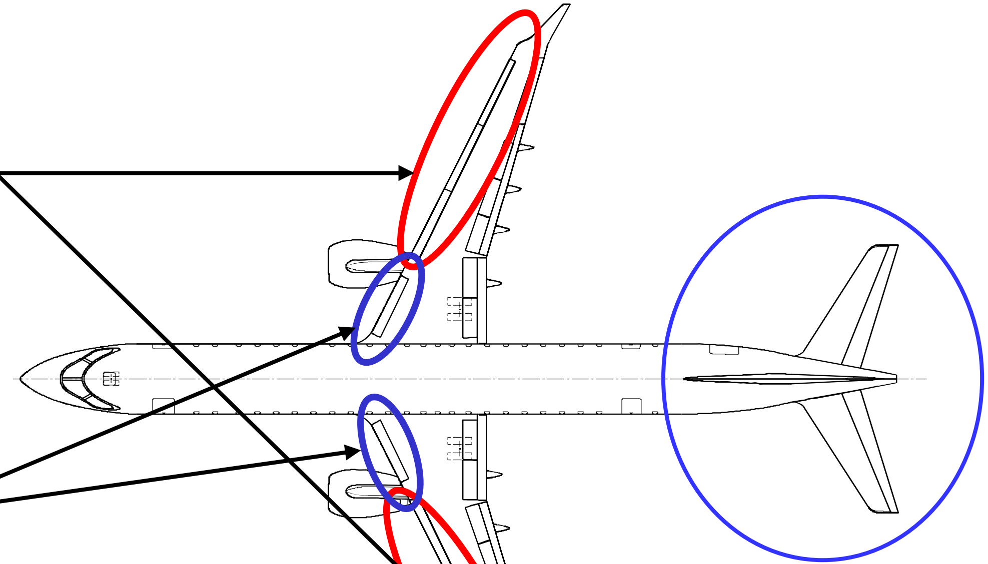
4.0 Introduction of MRJ

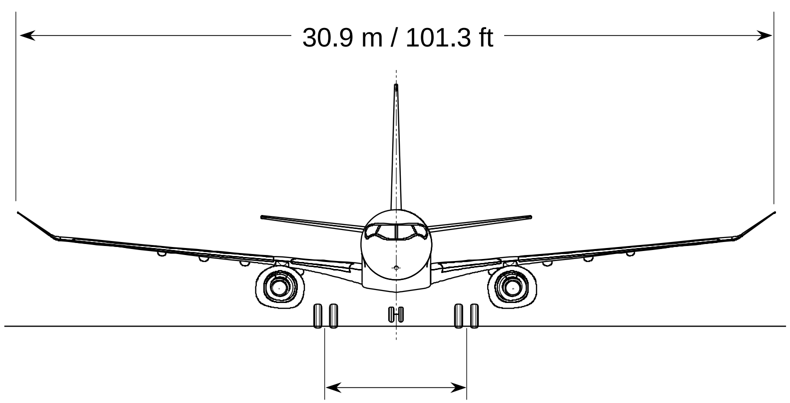
4. Introduction –MRJ-90

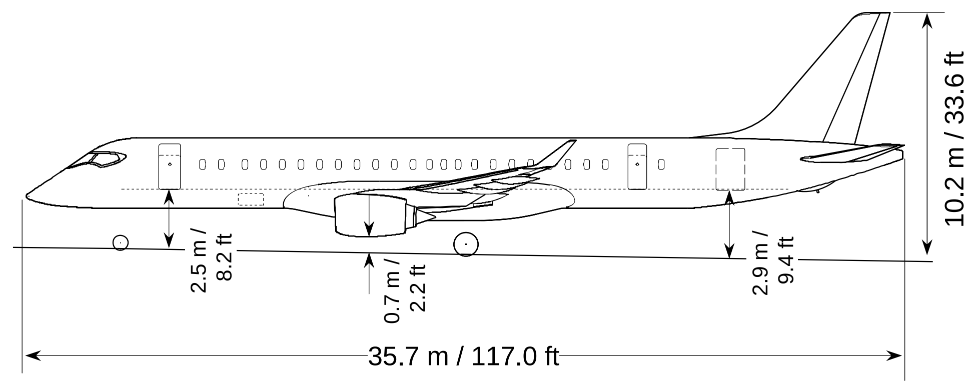
Outboard L/E slats are equipped with anti-/de-icing system.

Necessity of ice protection system for inboard slats is still under study

Empenage is planned to be unprotected.





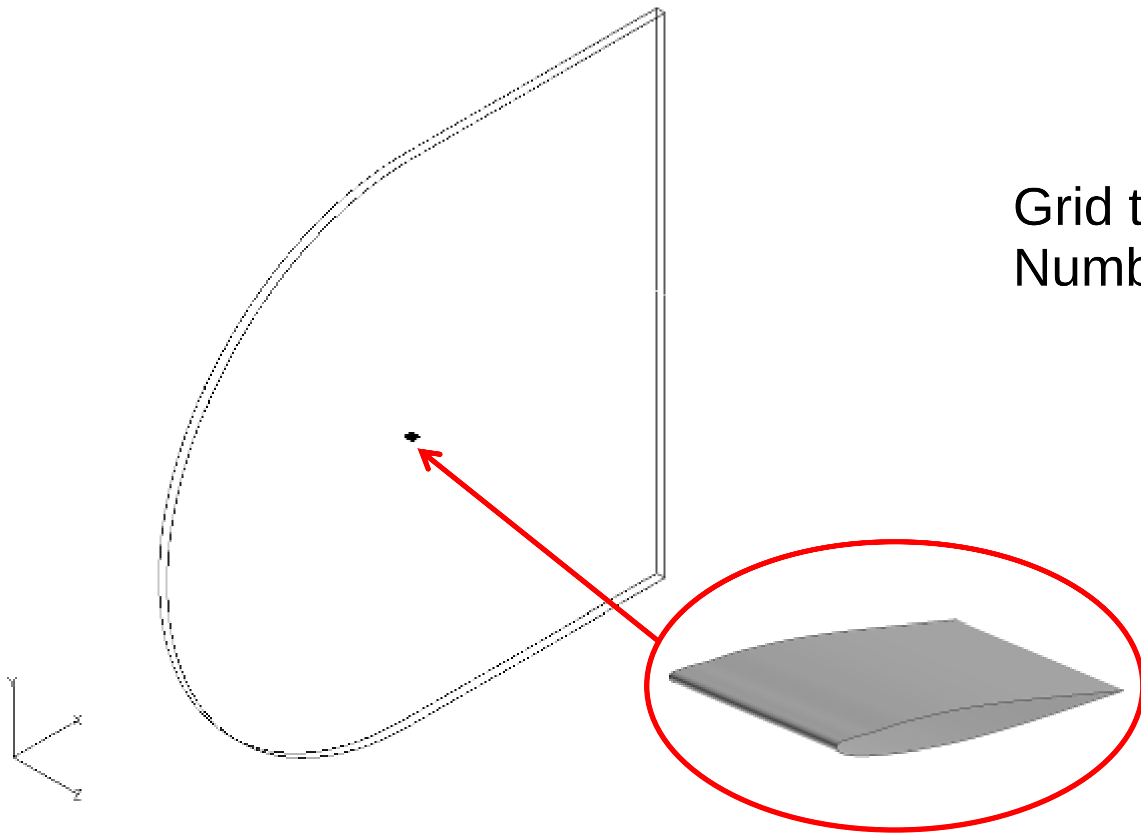


4. Application to Horizontal Stabilizer

4.1 2 Dimensional Airfoil

4. Application to Horizontal Stabilizer

4.1.1 Grid - 2 Dimensional Airfoil

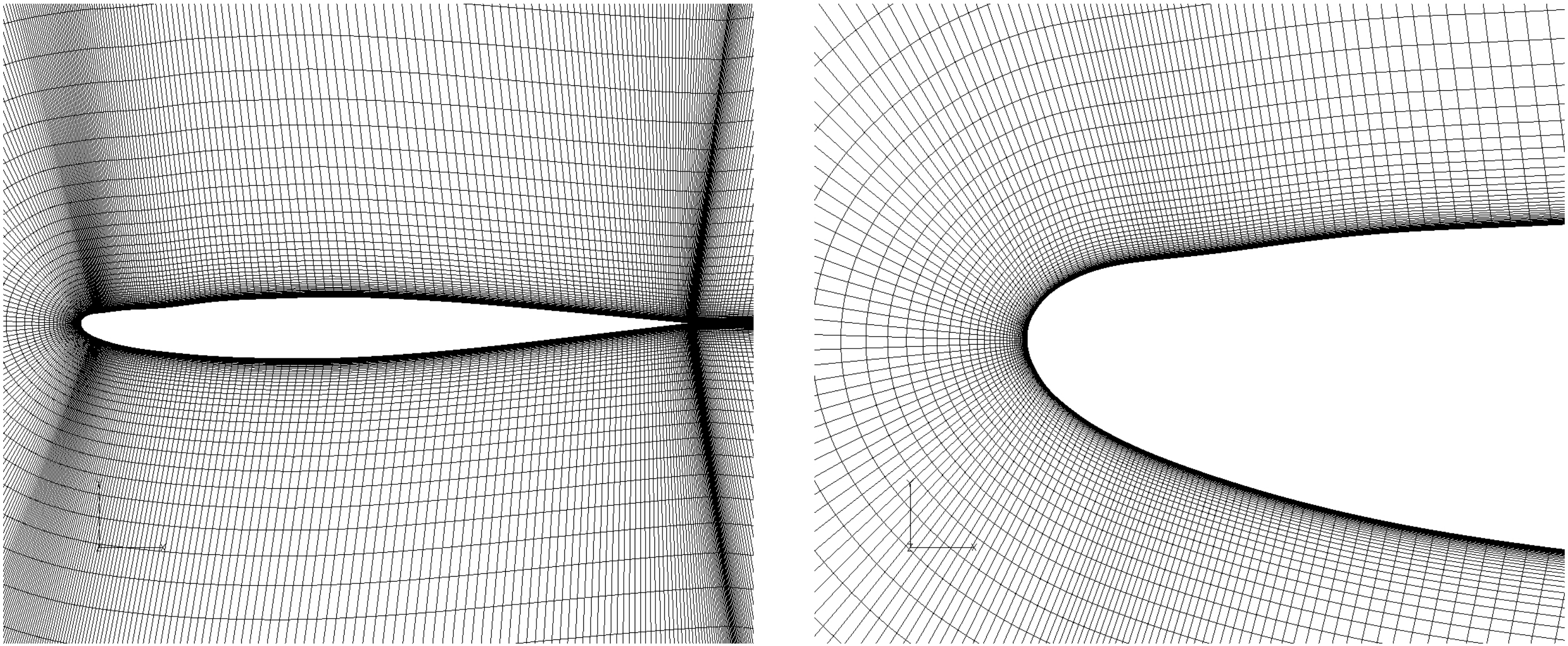


Grid type : structured grid
Number of grids : 57 thousands

Number of z direction grid is 1 to simulate 2D field.

4. Application to Horizontal Stabilizer

4.1.1 Grid - 2 Dimensional Airfoil



Computation Grid

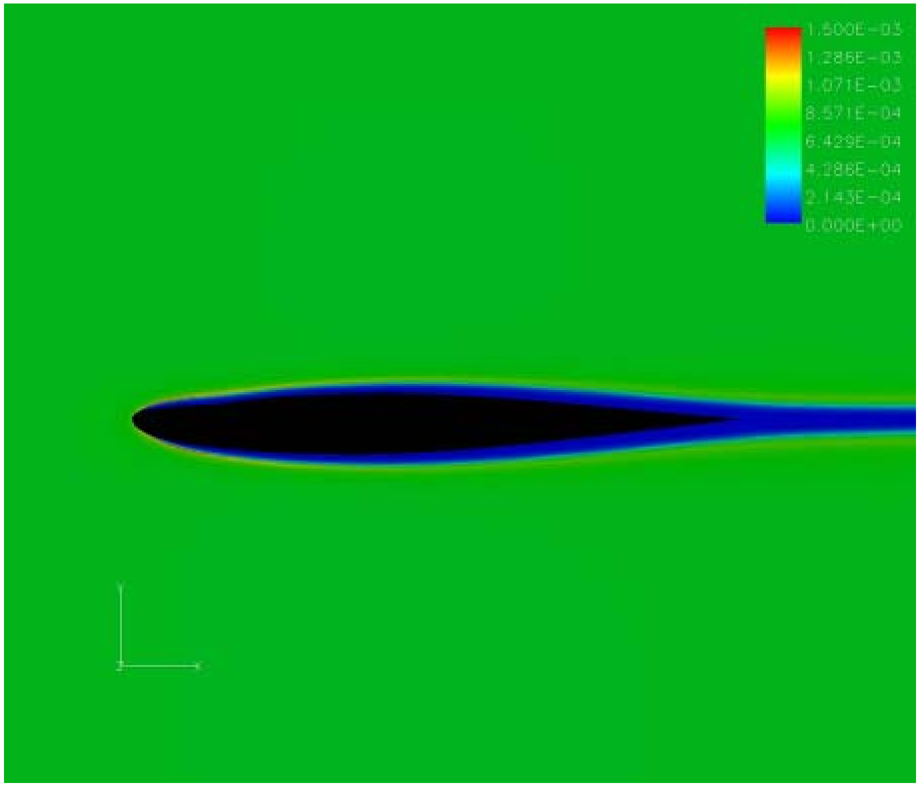
4. Application to Horizontal Stabilizer

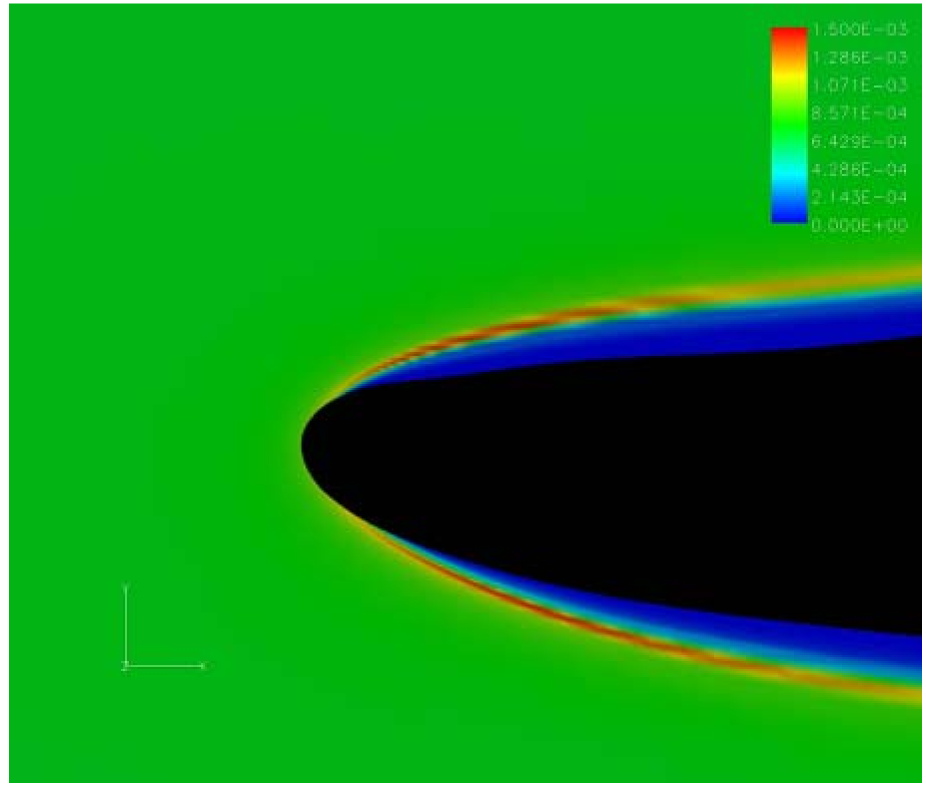
4.1.2 Flow Conditions - 2 Dimensional Airfoil

- Altitude 10,000ft
- Velocity 137m/sec
- Static Temperature 268.15K
- AoA 0deg.
- Continuous Maximum Holding Time : 45 minutes
- MVD and LWC from 14CFR part25 Appendix C
  15μ and 0.7 g/m^3
- Chord Length 1.1m and 2.1m

4. Application to Horizontal Stabilizer

4.1.3 Results - 2 Dimensional Airfoil

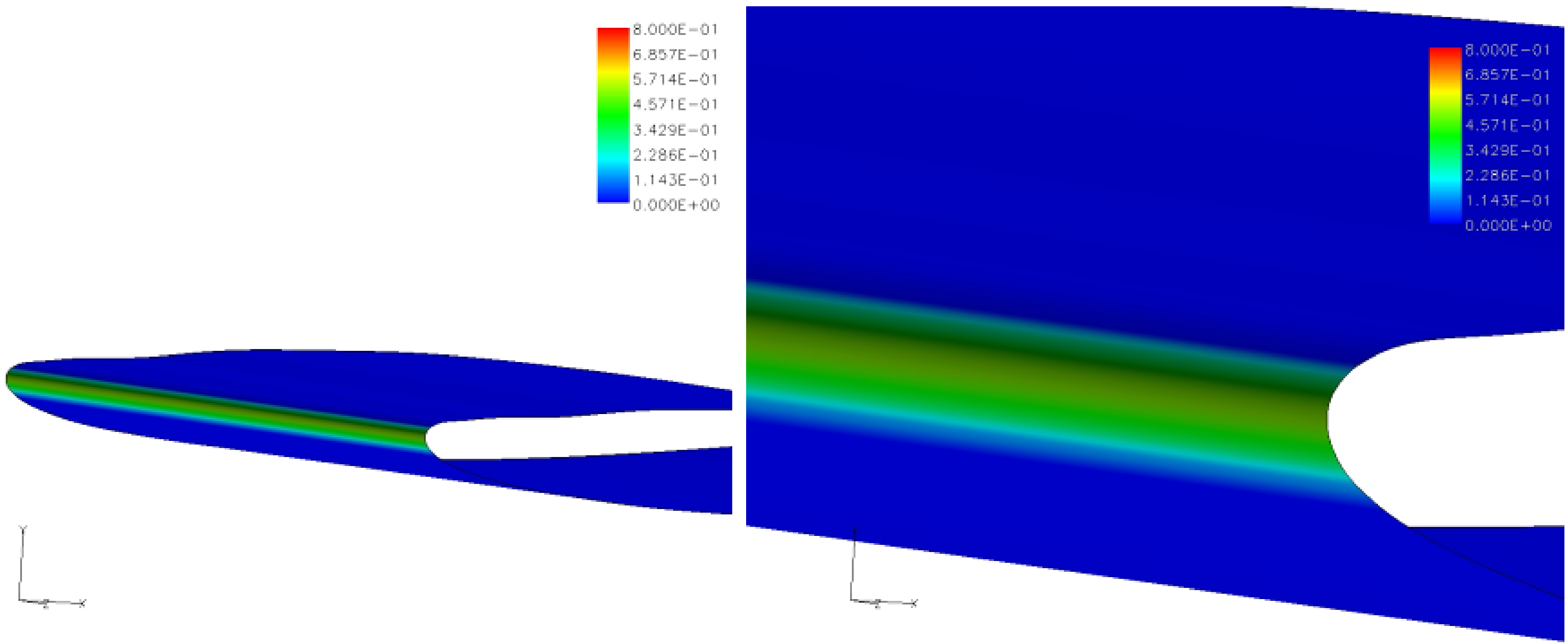




LWC [kg/m^3] (case7)

4. Application to Horizontal Stabilizer

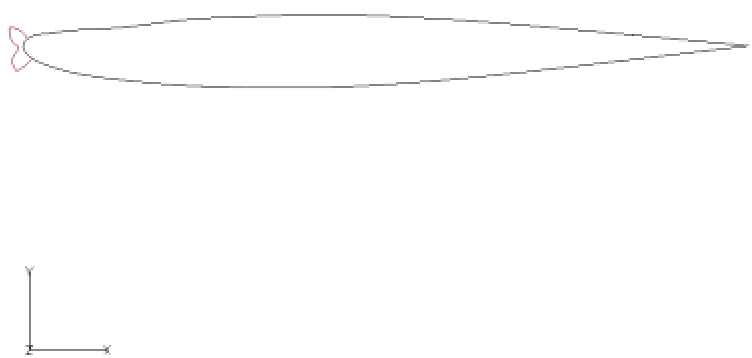
4.1.3 Results - 2 Dimensional Airfoil

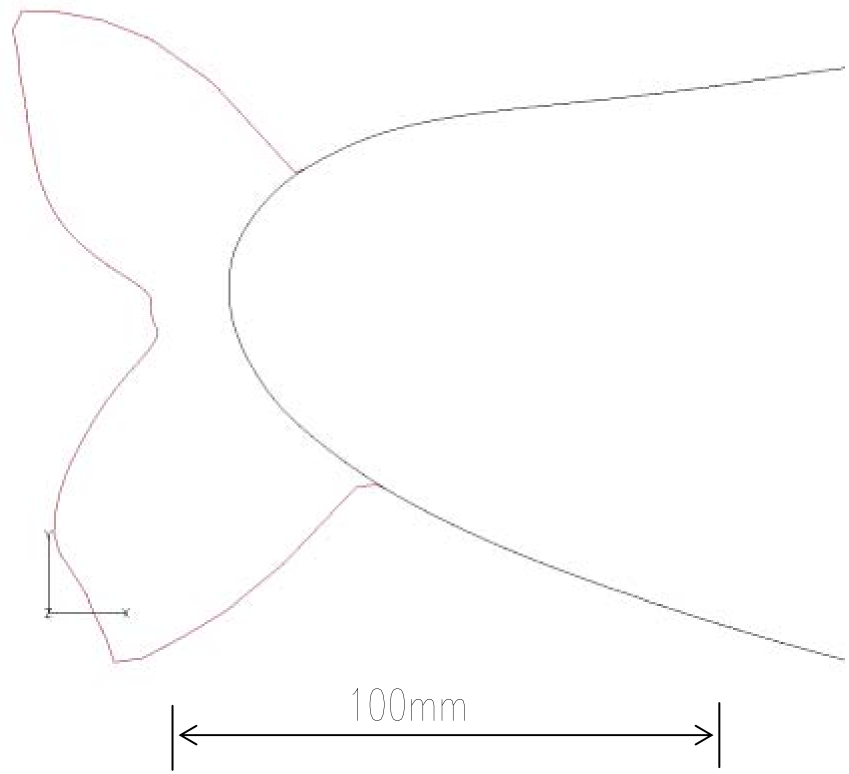


Collection Efficiency [-] (case7)

4. Application to Horizontal Stabilizer

4.1.3 Results - 2 Dimensional Airfoil





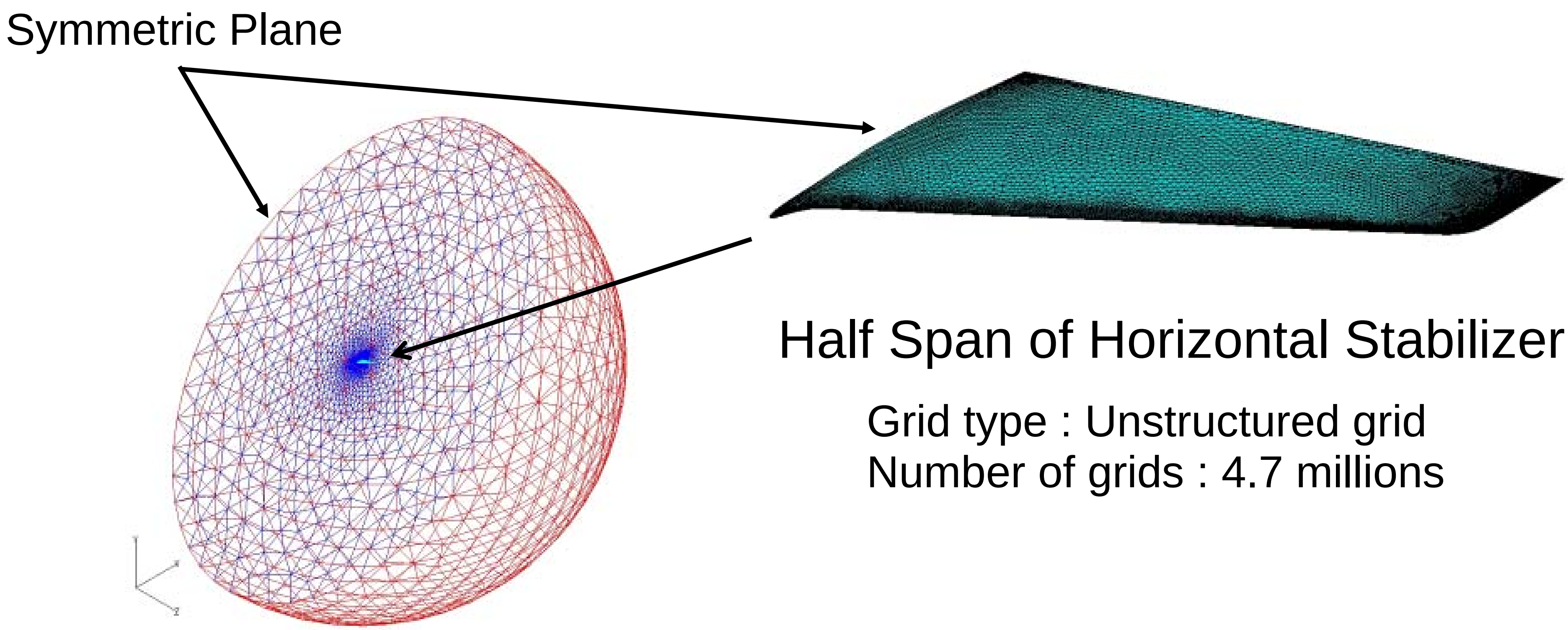
Ice Shape (Case7: AoA 0deg, 2.1m chord)

4. Application to Horizontal Stabilizer

4.2 3 Dimensional Airfoil

4. Application to Horizontal Stabilizer

4.2.1 Grid - 3 Dimensional Airfoil



Grid type : Unstructured grid
Number of grids : 4.7 millions

4. Application to Horizontal Stabilizer

4.2.2 Flow Condition - 3 Dimensional Airfoil

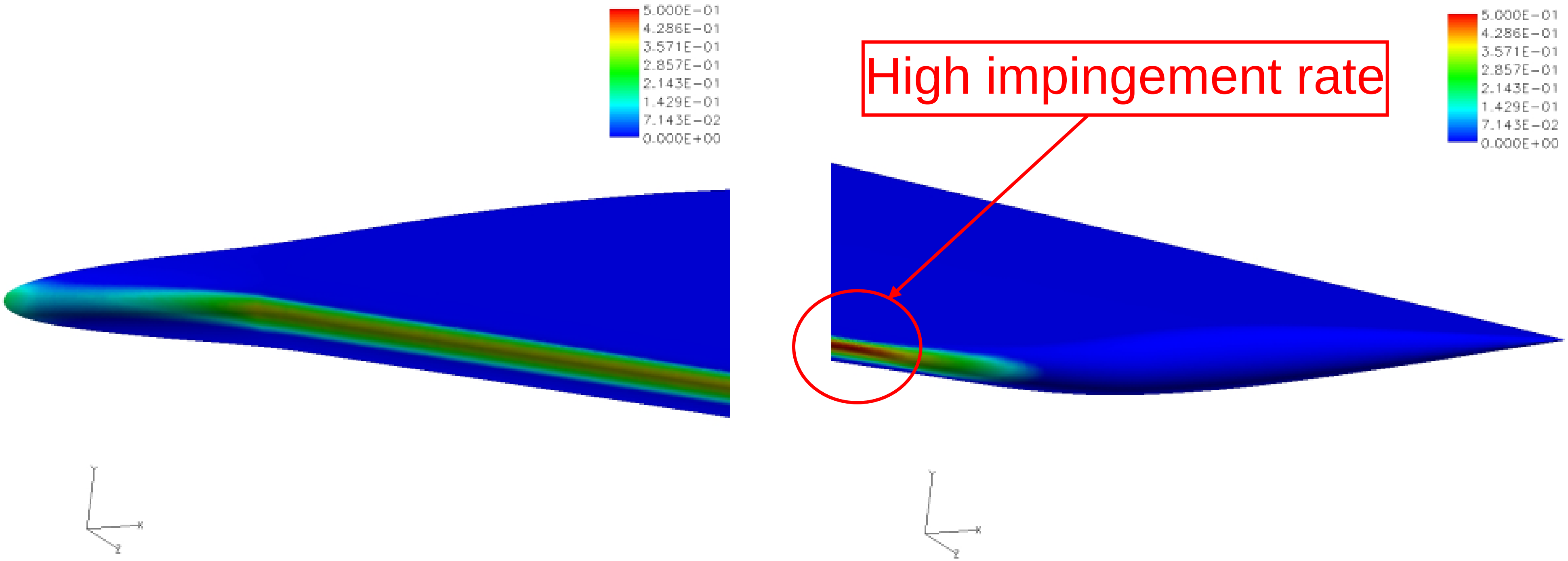
The same condition with 2 dimensional airfoil analysis.

↓

- Altitude 10,000ft
- Velocity 137m/sec
- Static Temperature 268.15K
- AoA 0deg.
- Continuous Maximum Holding Time : 45 minutes
- Minimum MVD from 14CFR part25 Appendix C
  15μ and 0.7 g/m^3

4. Application to Horizontal Stabilizer

4.2.3 Results - 3 Dimensional Airfoil

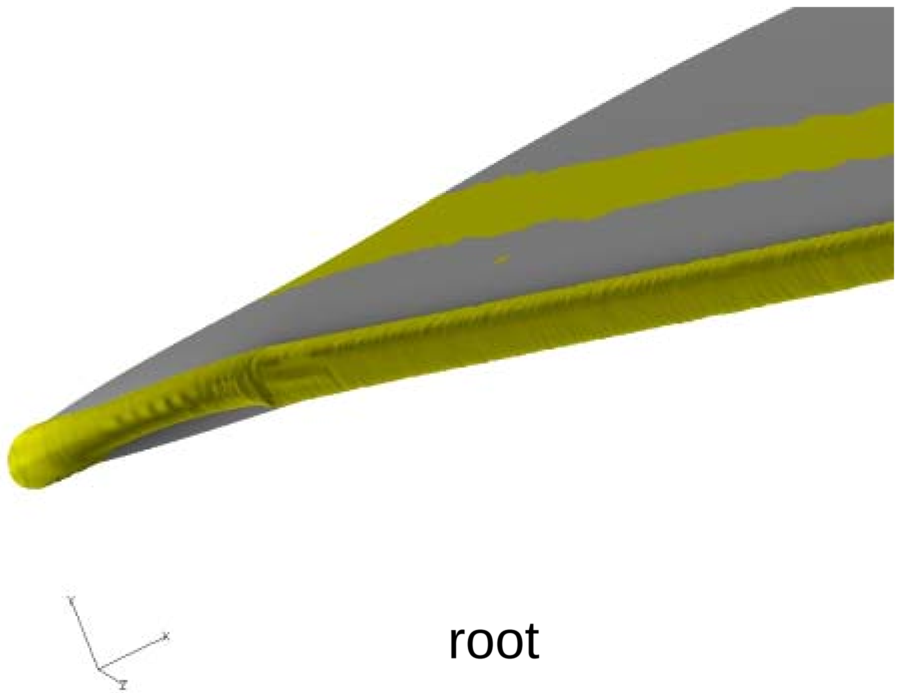


root tip

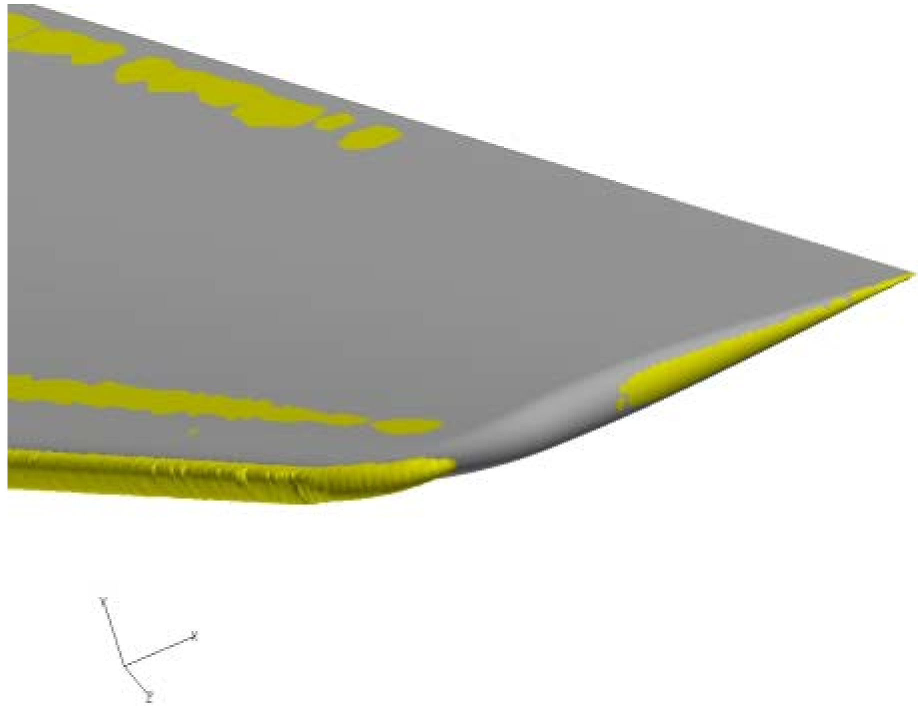
Collection Efficiency Contour

4. Application to Horizontal Stabilizer

4.2.3 Results - 3 Dimensional Airfoil



root

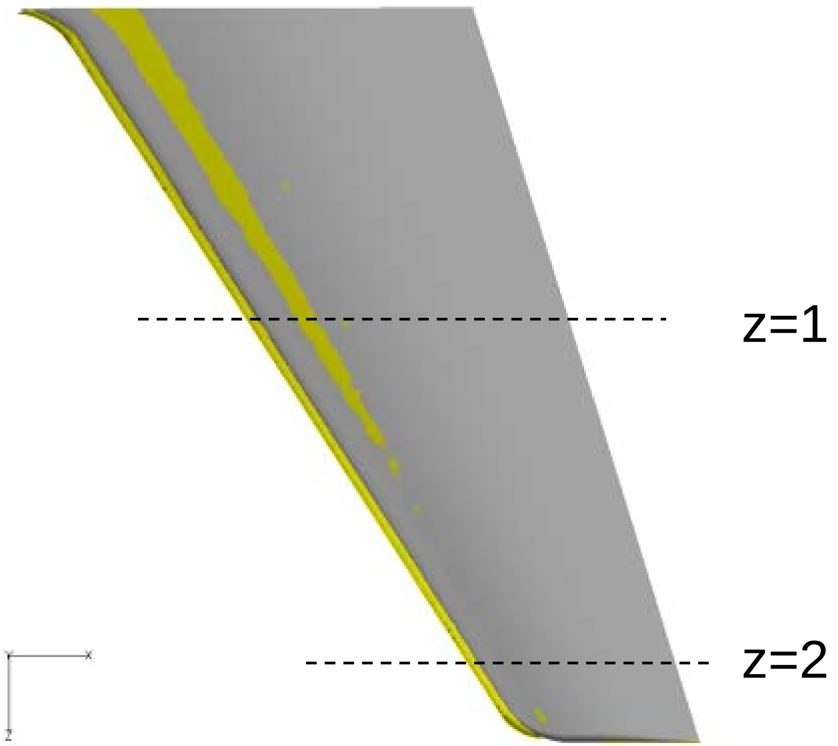


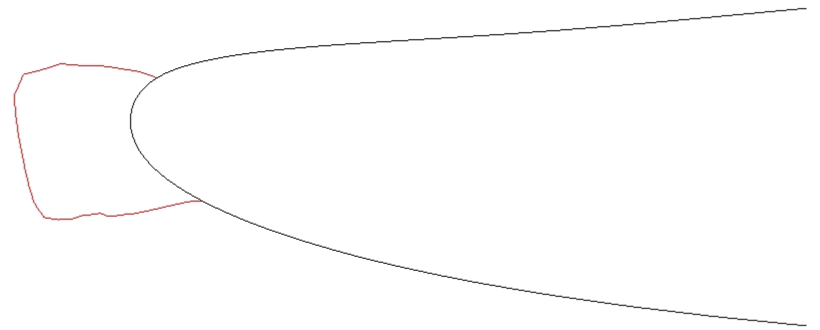
tip

Ice Shape

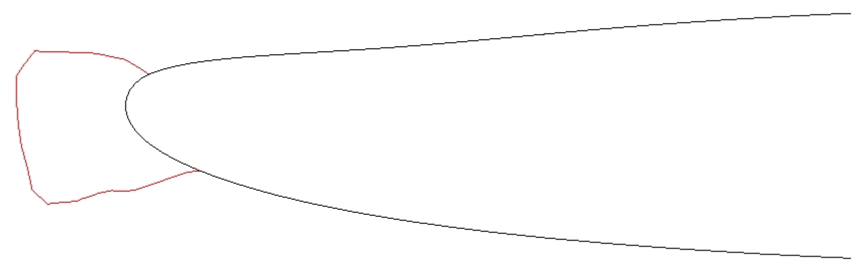
4. Application to Horizontal Stabilizer

4.2.3 Results - 3 Dimensional Airfoil





z=1



z=2

Ice Shape (Cross Sectional)

4. Application to Horizontal Stabilizer

4. 3 Summary

- In case of 3D calculation, double horns didn't build up in spite of the condition in which double horns build up in 2D calculation.

- One possible reason is that the span-wise flow near the leading edge may have strong effect on the computed ice shape.

- More studies in modeling 3D ice shape is necessary including mesh refinement and turbulence model.

- Since there is no experimental data in this airfoil, icing wind tunnel test should be conducted and the validation with experimental result is necessary in the near future.

5. Conclusions

- Validation results of FENSAP-ICE are presented.
- The results from droplet impingement solver, ice accretion solver are presented.
- In droplet impingement analysis, the solution from FENSAP and LEWICE has similar tendency.
- As for the ice accretion analysis, two shot calculation gives relatively good results.
- More study is necessary in 3D ice accretion analysis.

5. Conclusions (cont.)

- In order to be applied to type certification process, more validation works should be conducted.
- As a further study, icing wind tunnel test to obtain the ice shape on MRJ wing is planned.

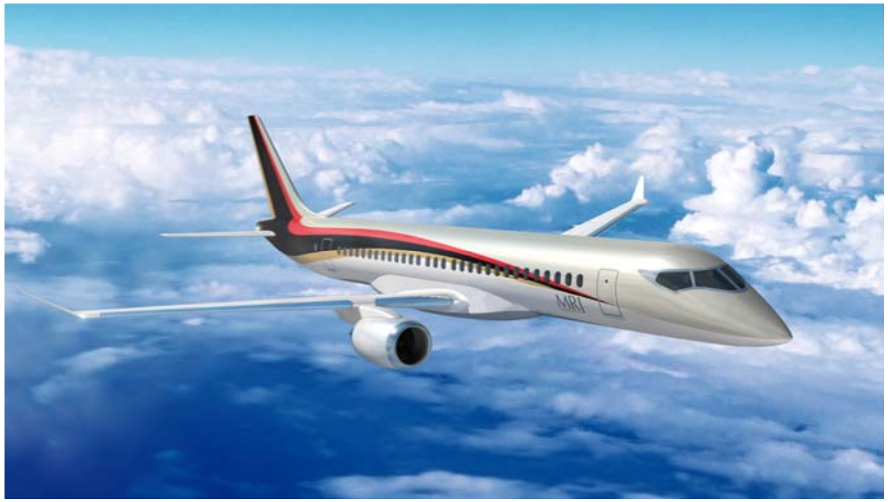
MITSUBISHI HEAVY INDUSTRIES, LTD.

Acknowledgment

- Japanese authors would like to acknowledge
  - Mr. Eugene Hill
  - Mr. Larry Timmons

  for their many technical supports and
  - New Energy Development Organization, Ministry of Economy, Trade and Industries of Japanese Government

  for their support in funding.



Thank you very much for your attention !