Politecnico di Milano
Facoltà di Ingegneria
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Dipartimento di Scienze e Tecnologie Aerospaziali

Blowing Snow in Aeronautical Application: a new Statistical Model by means of Bayesian Approach

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Contents

Chapter 1

Introduction

1.1 The *Snow Problem* for in-flight ice accretion

Why studying the snow is relevant for in-flight ice accretion. What PoliMIce (PoliDrop) needs from this study: $c_D(Re, param)$ formula and a rule to choose the parameters.

1.2 State of Art

1.2.1 Non-spherical particles

Introduction to available models: nothing generated precisely for snow application but many models present for arbitrary-shaped particles. Generally the models are validated using particles with various known shapes, but not with snowflakes.

Generic model formula: $c_D = c_D(d_{\mathrm{v}}, Re, \underline{\Phi})$

Models and Experiments examples
Explanation of figures like 1.1 and 1.2.

1.2.2 Snow experiments

Introduction to available snow experiments. For aerodynamic purposes the most relevant type of measure is the ground experiment conducted with some kind of disdrometer. It gives a measure the particle dimension (often its mean diameter) and a measure of its terminal velocity.

1.3 Blowing vs Falling regime

Problem with the difference between the regime of the simulations and the regime of the experiments. Our assumption: the model we chose is able to transfer the information about the shape of the particle from the falling to the blowing regime.

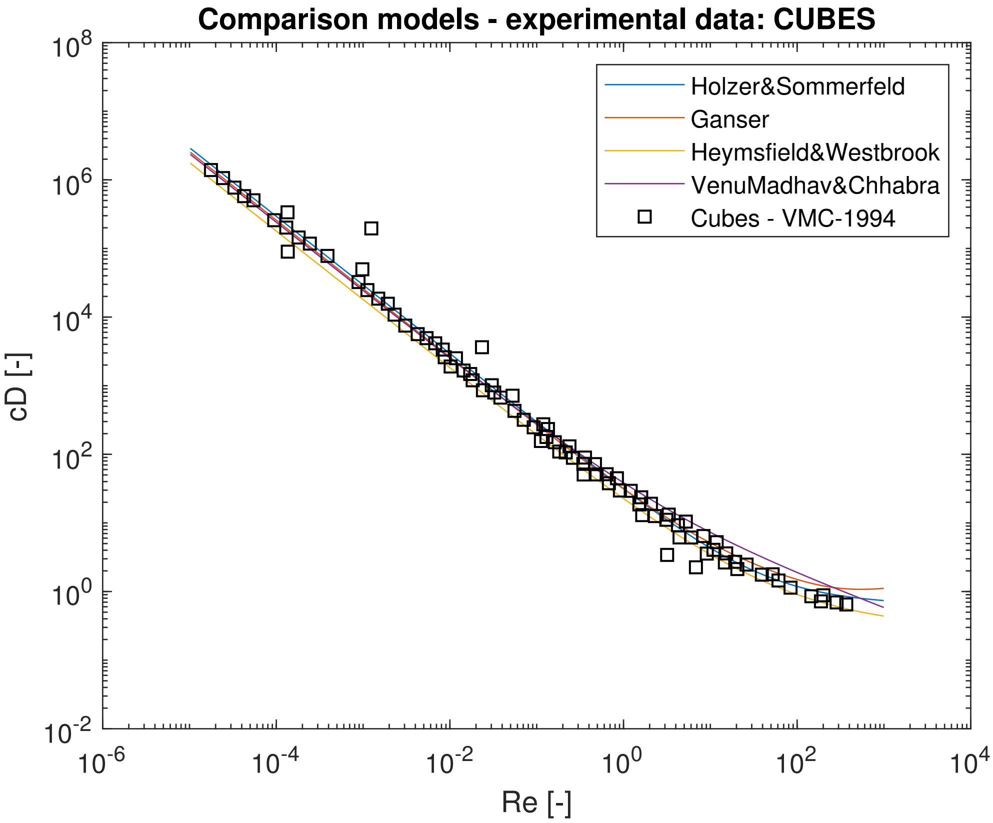


Figure 1.1

1.4 Research Question

Goal of the thesis: The question proposed in Section 1.1 will be answered by:

1. Choose a suitable model for the description of the snow c_D
2. Use that model to infer the statistical distribution of the shape parameters of a given *cloud* in the *falling regime*
3. Transfer this information to the *blowing regime* by implementing the same model with the same parameter distribution in PoliDrop

1.5 Structure of the thesis

Chapter description

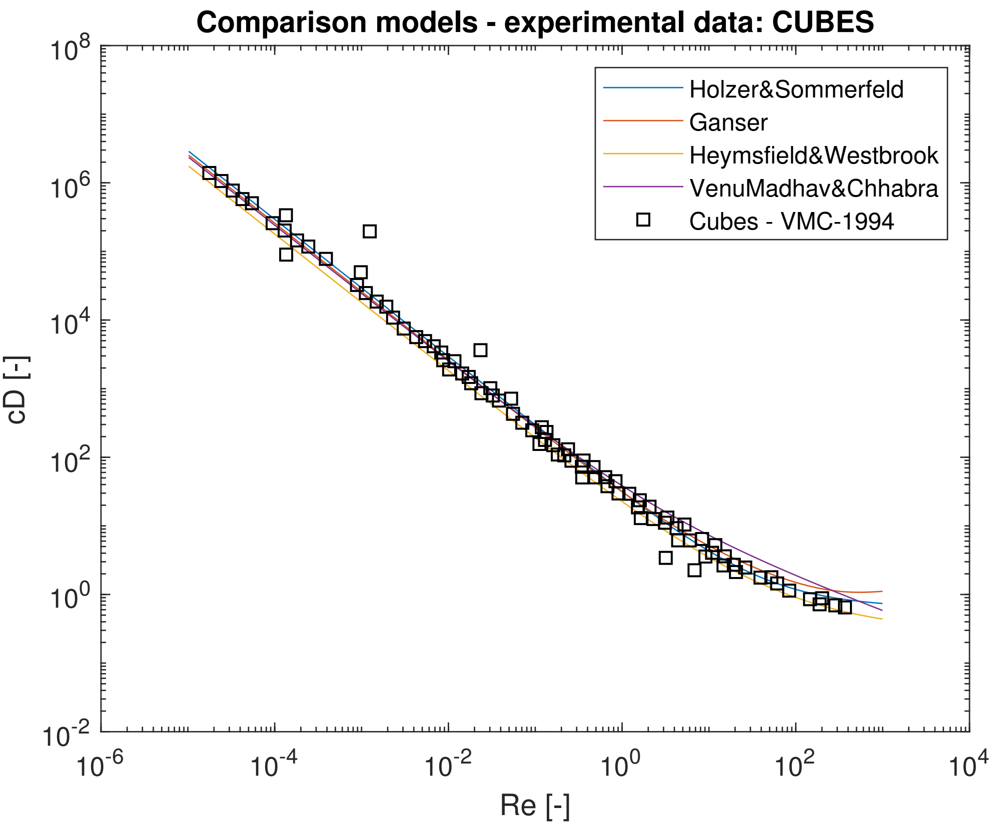

Comparison models - experimental data: CUBES
Holzer&Sommerfeld
Ganser
Heymsfield&Westbrook
VenuMadhav&Chhabra
Cubes - VMC-1994
cD [-]
Re [-]
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}

Figure 1.2

Chapter 2

Review of Falling-Snow Models

In this chapter the theoretical framework behind a general drag coefficient model will be explained and a review of the available models in literature will be proposed.

Recalling from 1.2.1, the formula used for these models is the following:

$$c_D = c_D(d_\mathrm{v}, Re, \underline{\mathit{\Phi}}) \tag{2.1}$$

The characteristic dimension of the particle (d_v)

Generic non-spherical particle model description.
formula (recalled from intro)
Principal shape parameters

2.1 Chhabra review

The models must provide information on 2 main aspect: *shape* of the particle (sphericity) and *orientation* of the particle. (Chhabra)

2.2 Ganser - 1993

Description of the Ganser model (The best up to 1993).

2.3 Heymsfield and Westbrook - (2004)

Description of the model ans why it doesn't work.

2.4 Holzer and Sommerfeld - (2008)

Description of the model and it's simplified form. Comparison with Ganser: sensitivity study on the parameters of both models and why H&S better suits the experimental curves of snow (+ "cite" the ICE GENESIS results proving that this model is the better one)

2.5 Model comparison

comparison between the models and justification of my choice.

2.6 Terminal Velocity calculation

Equation for the terminal velocity of a particle: how to calculate every term starting from the diameter and the shape parameters

Chapter 3

Parameter Estimation

3.1 Problem Formulation

Variables, unknown, data declaration.

3.2 Bayes Theorem

Theoretical background on Data Analysis using the Bayes approach. Choice of the prior and the likelihood to find the single, best parameter that explains a certain data set.

3.3 Gaussian Mixture Model

Need of a multi-modal distribution of the parameter: in a cloud more that one type of shape can be present. Modification of the Likelihood function using GMMs.

3.4 Numerical Implementation

General scheme of the program: Iteratively increase the number of mode allowed up to a certain convergence criterion (Da vedere con Giulio)

3.4.1 Maximization of the Posterior/Likelihood

Calculation of a single posterior element

- brute force algorithm
- optimization (Genetic Algorithm)
- Markov-chain method (?)

Chapter 4

Results

4.1 Test case 1 - Code Verification

Verification with totally artificial data set

- 1 parameter (Figure 4.1, 4.2, 4.3, 4.4)
- 2 parameters (Figure 4.5, 4.6, 4.7)

4.2 Test case 2 - Experimental Dataset

Brief description of the available experimental campaigns (Brandes + other 2 references) and their limitations.

4.2.1 Brandes Experimental campaign

Description of the Brandes results and impossibility to use the raw data

4.2.2 Data Set generation

Generation of an artificial data set starting from the relations discovered by Brandes. The dependency on the diameter distribution is not taken into account as it can be retrieved a posteriori.

4.2.3 Application to the Brandes data set

- Example for 1 diameter interval
- Shape parameters - diameter distribution (Work in progress)

4.3 Test case 3 - Let it snow!

Falling snow test case (Check the terminal velocity distribution) with PoliDrop

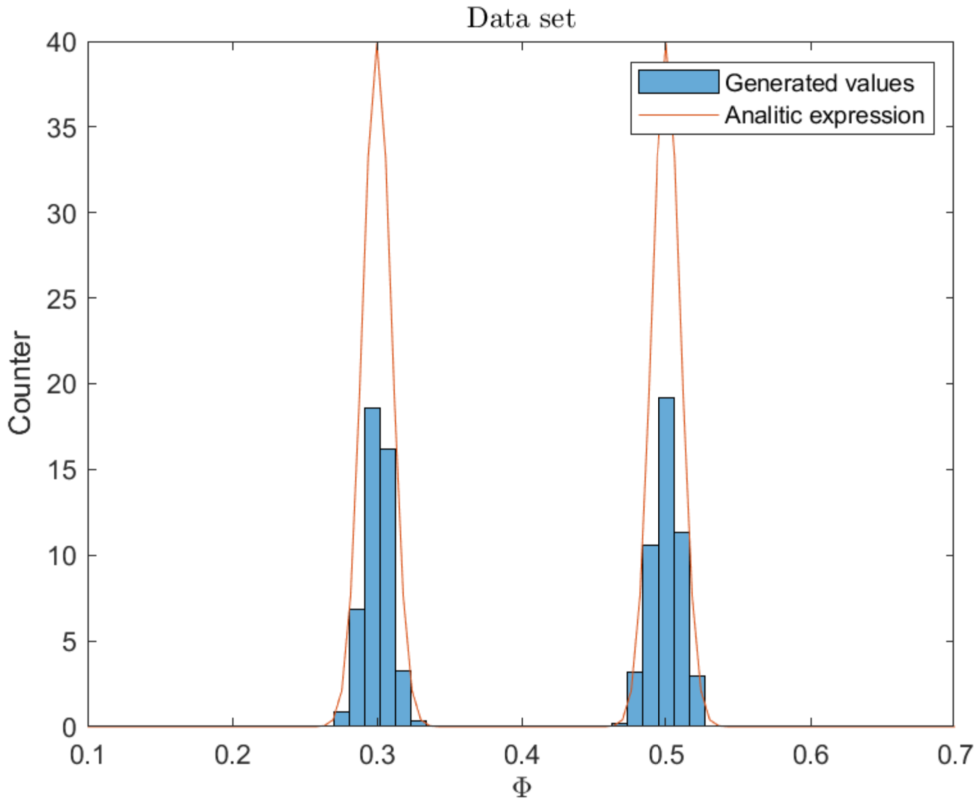

Data set
Generated values
Analitic expression
Counter
Φ
0
5
10
15
20
25
30
35
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Figure 4.1

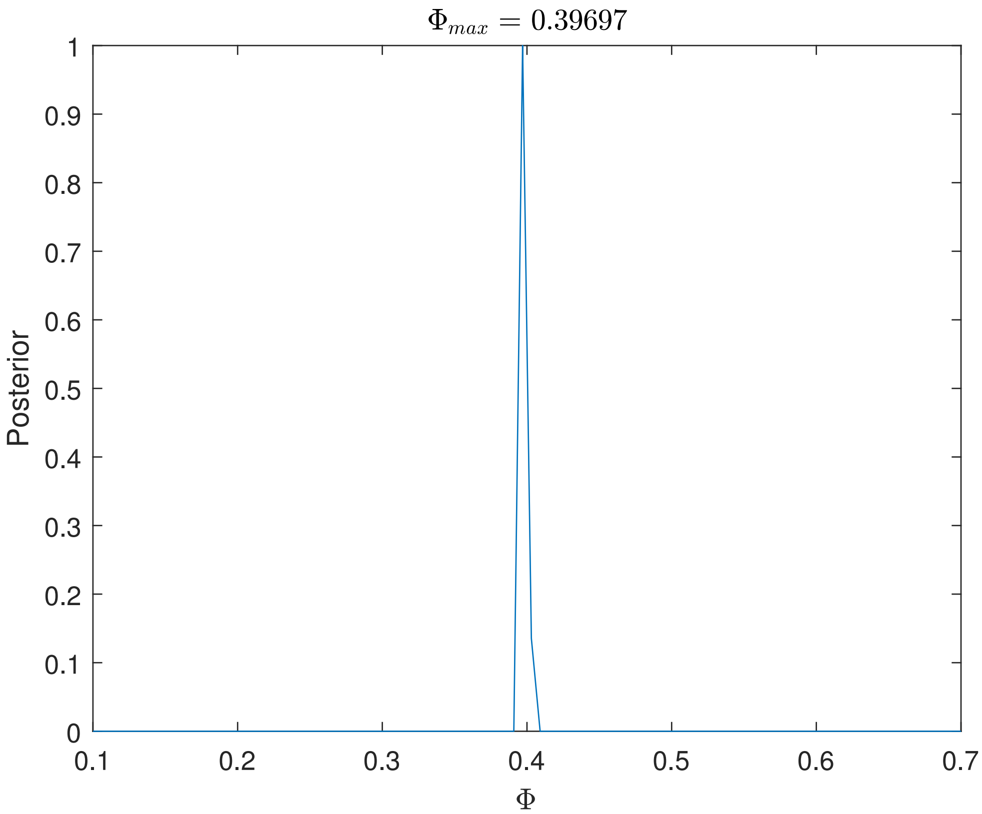
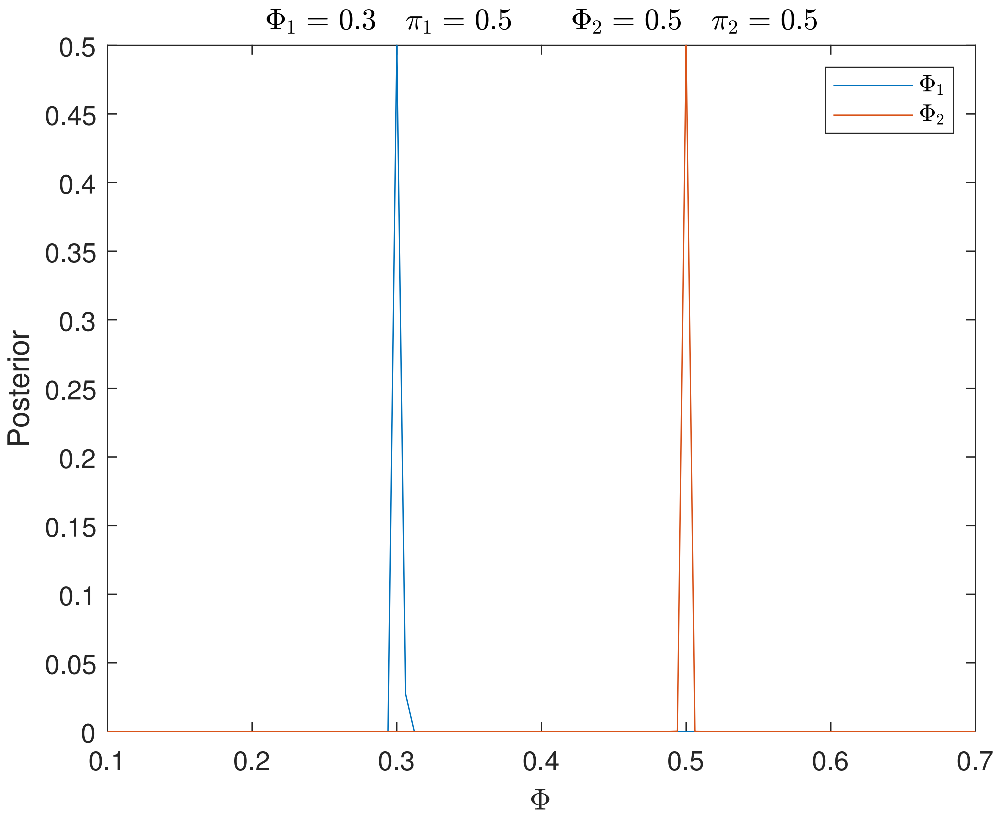

$\Phi_{max} = 0.39697$
Posterior
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Φ

Figure 4.2



$\Phi_1 = 0.3 \quad \pi_1 = 0.5 \qquad \Phi_2 = 0.5 \quad \pi_2 = 0.5$
Posterior
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Φ
Φ_1
Φ_2

Figure 4.3

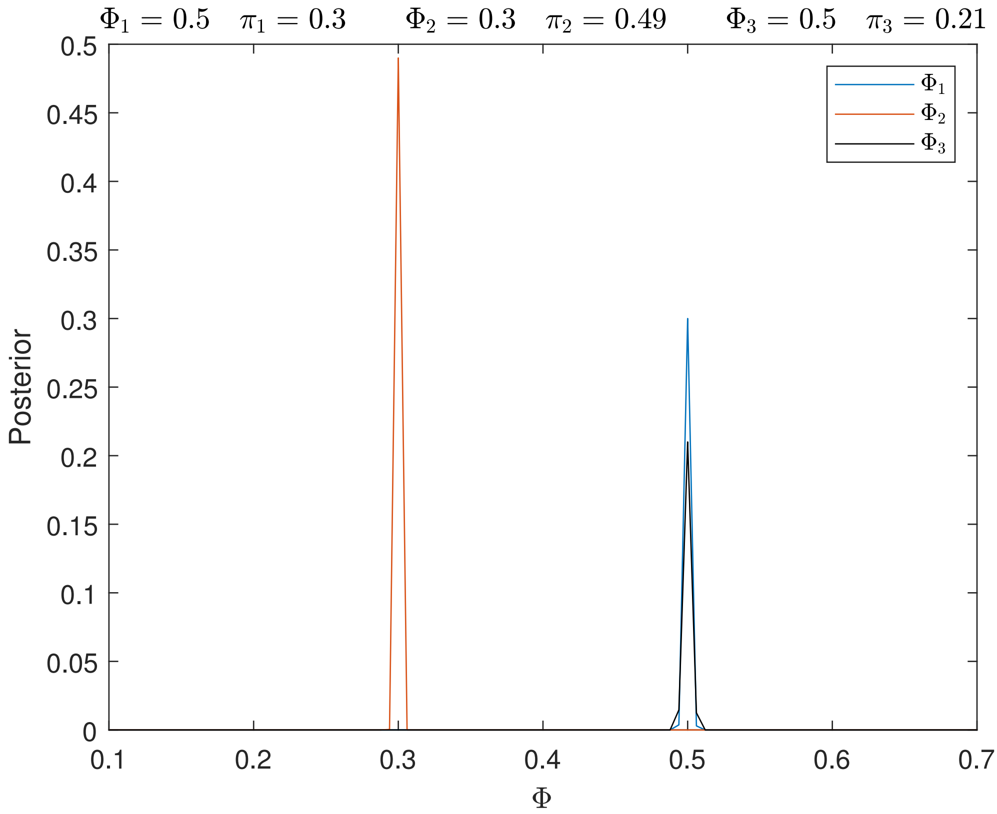


Figure 4.4

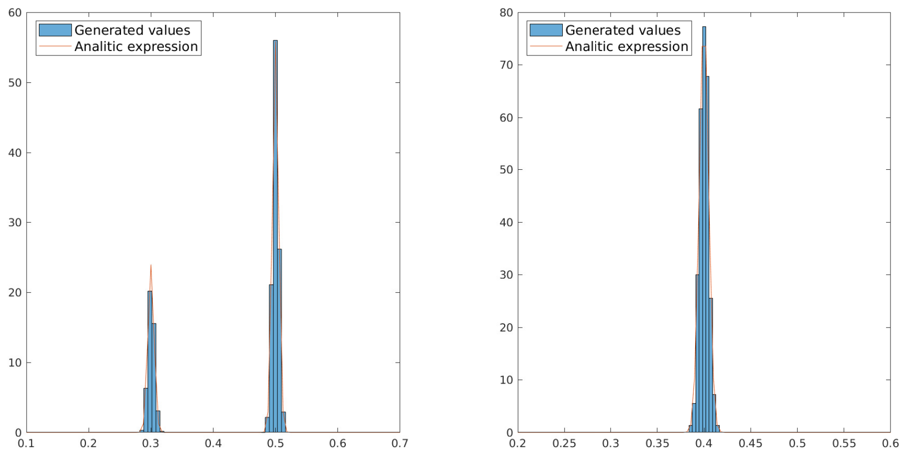


Figure 4.5

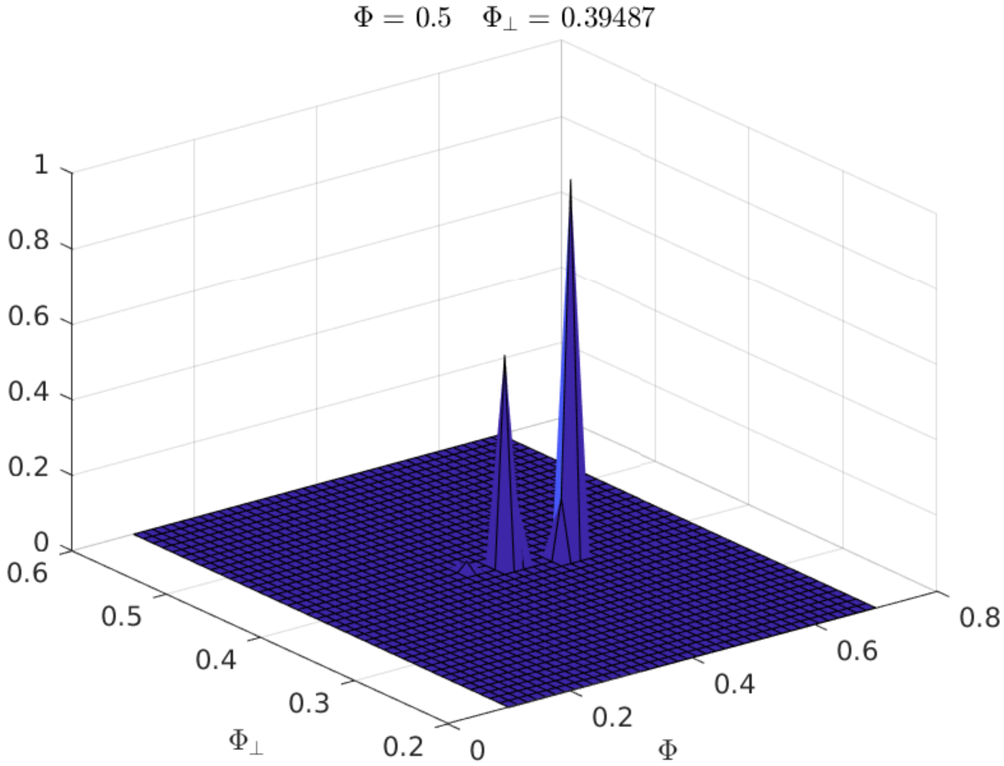


Figure 4.6

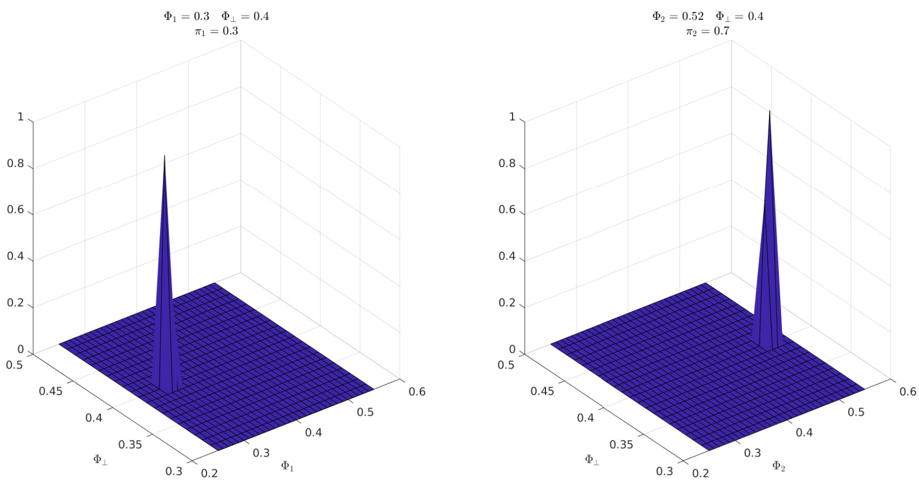


Figure 4.7

Chapter 5

Application to In-Flight Ice Accretion

5.1 PoliDrop

Description of PoliDrop Implementation of the chosen formula for the c_D in PoliDrop

5.2 Cloud generation

Some rules to generate the cloud by PoliDrop

5.3 Blowing snow example

Blowing snow test case: β on a profile

Chapter 6

Conclusions and Future developments