Politecnico di Milano
Facoltà di Ingegneria
Corso di laurea in Ingegneria Aeronautica
Dipartimento di Scienze e Tecnologie Aerospaziali

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

Relatore: Prof. Alberto Guardone
Correlatore: Dott. Giulio Gori

Tesi di Laurea di:
Alessio Raimondi Matr. 900291

Anno Accademico 2019-2020

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 Non-spherical particles

Introduction to non-spherical particles models: types of models and experiments available (relative to a generic non-spherical particles) and the principal shape factors.

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

1.3 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.

1.4 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.

1.5 Problem Formulation

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

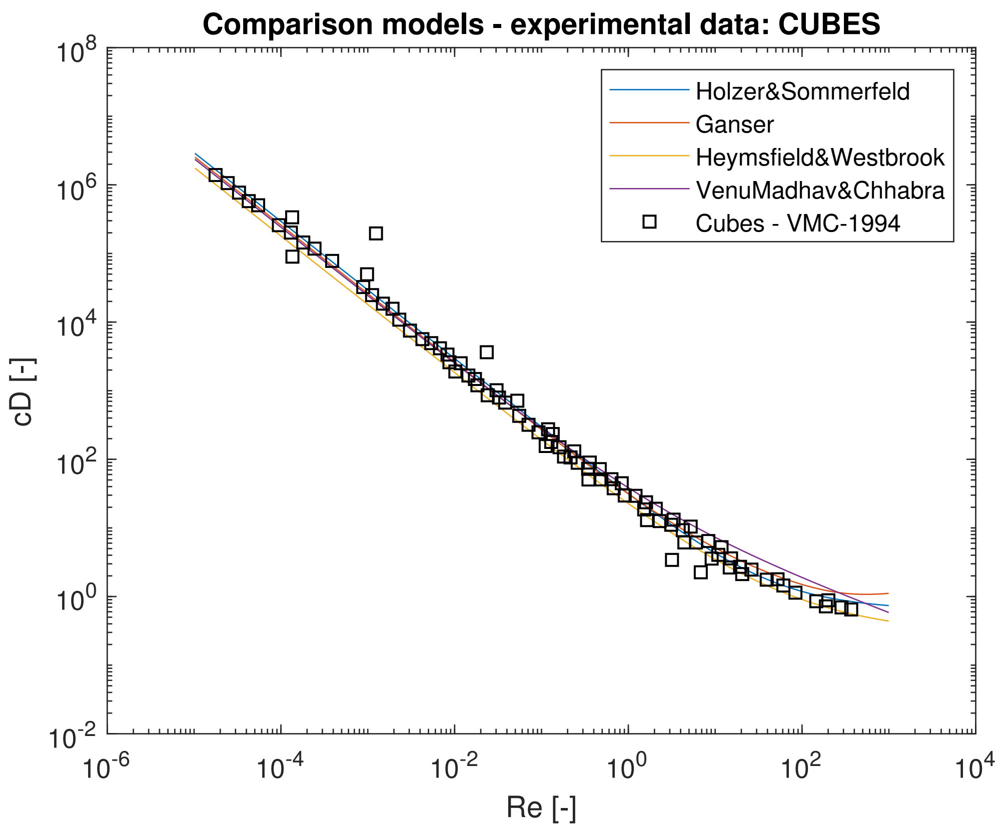


Figure 1.1

1. Find 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

1.6 Structure of the thesis

Chapter description

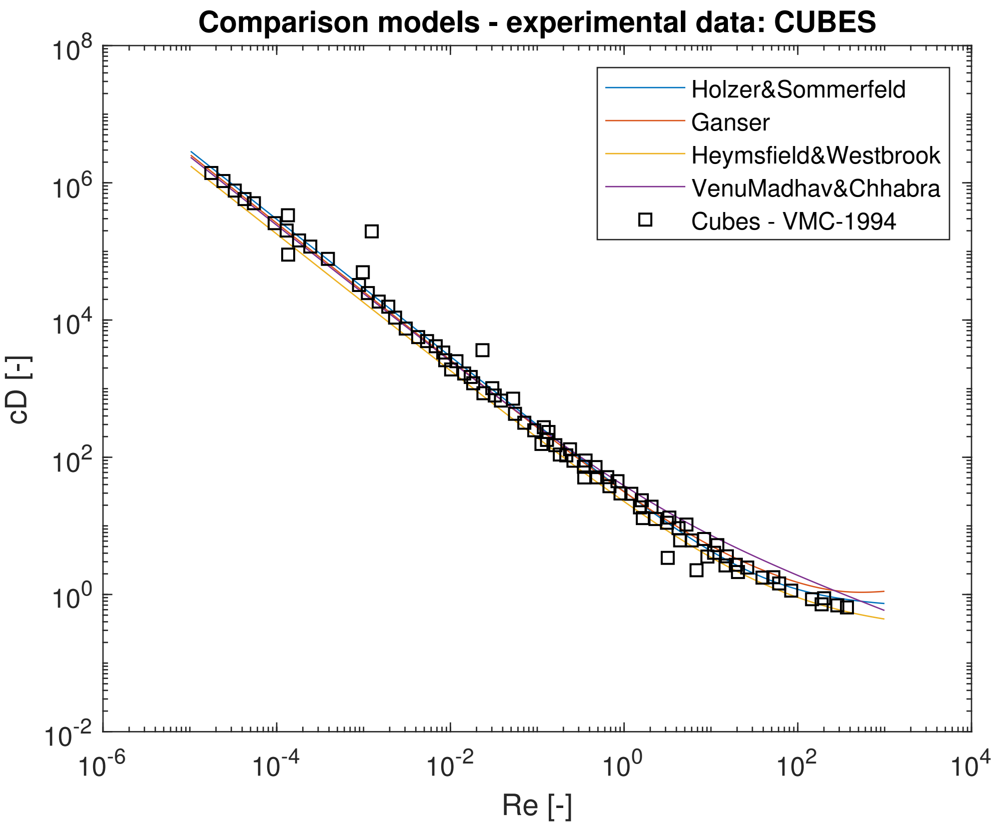

Comparison models - experimental data: CUBES
Holzer&Sommerfeld
Ganser
Heymsfield&Westbrook
VenuMadhav&Chhabra
Cubes - VMC-1994
cD [-]
Re [-]
10^8
10^6
10^4
10^2
10^0
10^-2
10^-6
10^-4
10^-2
10^0
10^2
10^4

Figure 1.2

Chapter 2

Choice of the Model

2.1 Chhabra review: Ganser

The models must provide information on 2 main aspect: *shape* of the particle (sphericity) and *orientation* of the particle. (Chhabra) Description of the Ganser model (The best up to 1993).

Description of the more recent models (2004? and 2008)

2.2 Heymsfield and Westbrook - (2004)

Description of the model ans why it doesn't work. (Do I need to talk about this model?)

2.3 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)

Chapter 3

Description of the Data Set

Type of information needed for the parameter estimation (d_v (some measure of the diameter), v_t (terminal velocity), σ (measurement error)).

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

3.1 Brandes Experimental campaign

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

3.2 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.

Chapter 4

Parameter Estimation

4.1 Problem Formulation

Variables, unknown, data declaration.

4.2 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.

4.3 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.

4.4 General scheme

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

Chapter 5

Numerical Implementation

5.1 Terminal Velocity calculation

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

5.2 Maximization of the Posterior/Likelihood

Calculation of a single posterior element

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

5.3 Code Validation

Validation with totally artificial data set

- 1 parameter (Figure 5.1, 5.2, 5.3, 5.4)
- 2 parameters (Figure 5.5, 5.6, 5.7)

5.4 Results

Application to the Brandes data set:

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

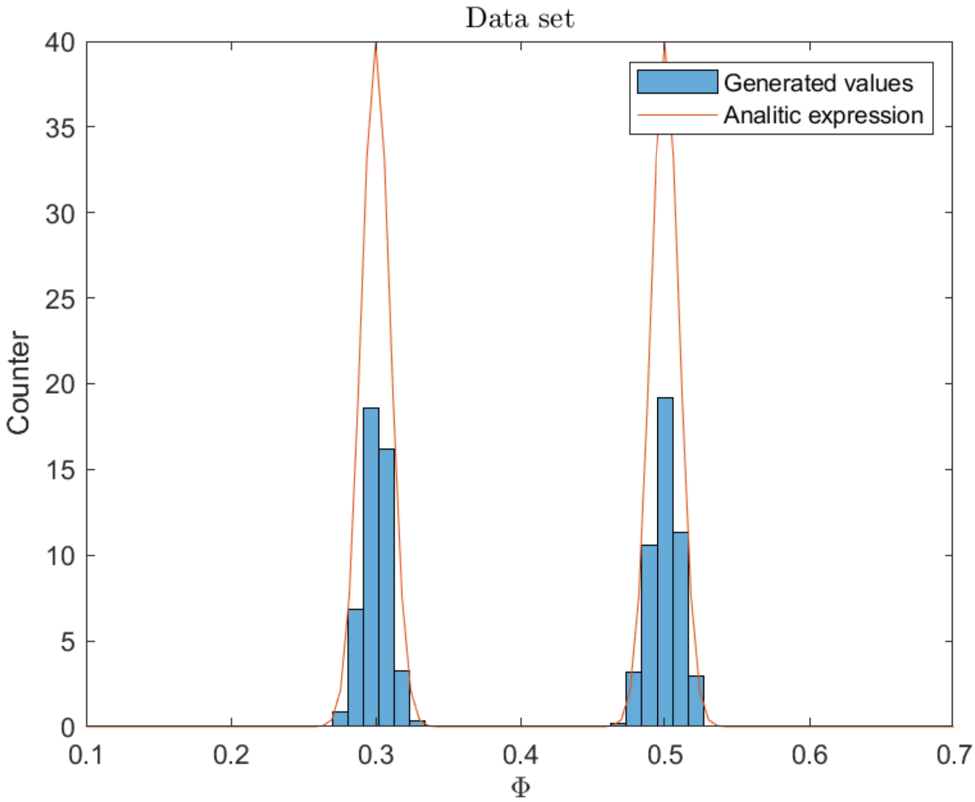

Data set
Generated values
Analitic expression
Counter
Φ
0
5
10
15
20
25
30
35
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Figure 5.1

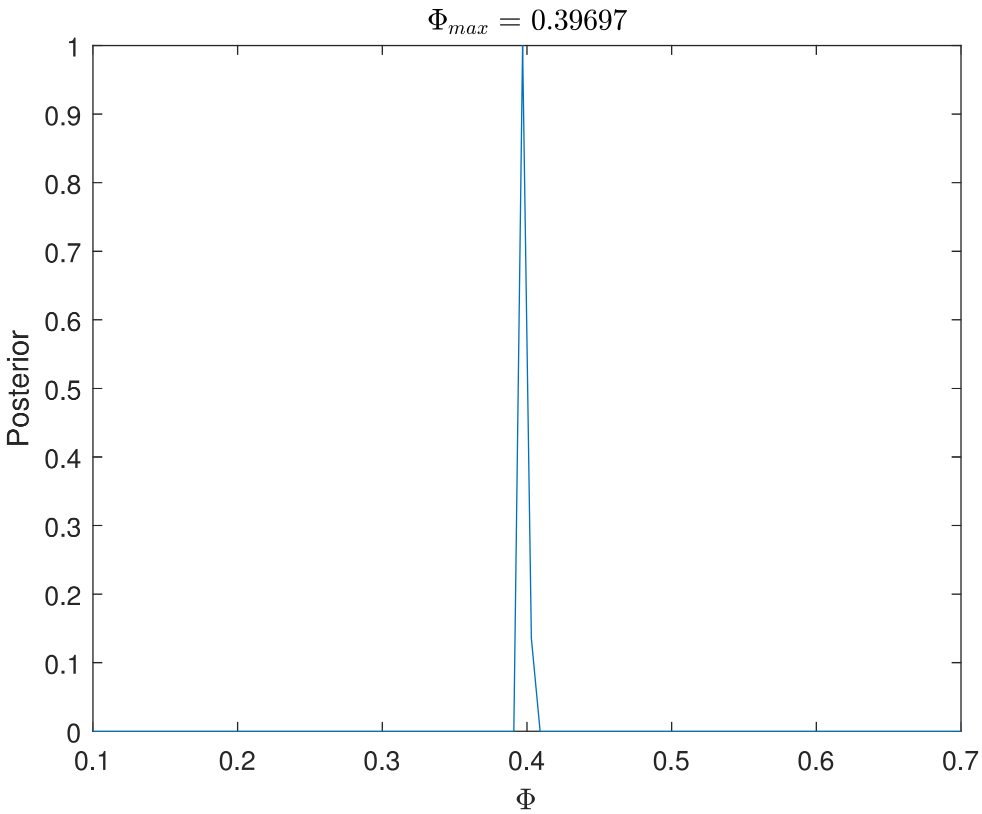
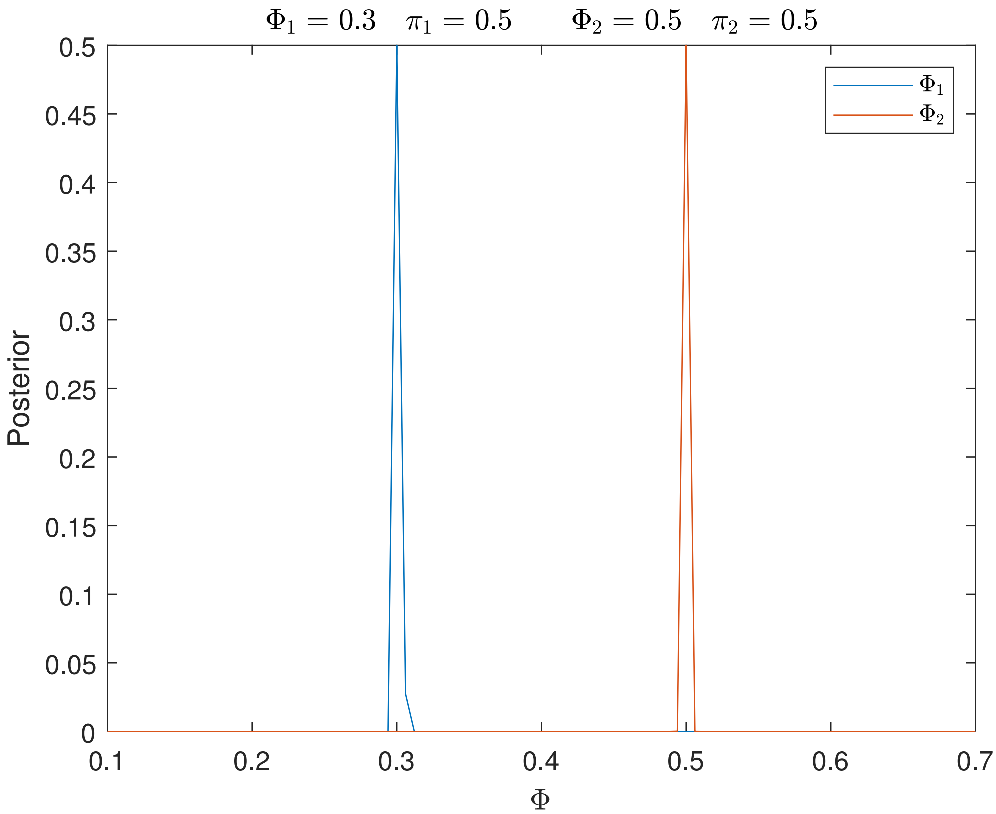

$\Phi_{max} = 0.39697$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Posterior
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Φ

Figure 5.2



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

Figure 5.3

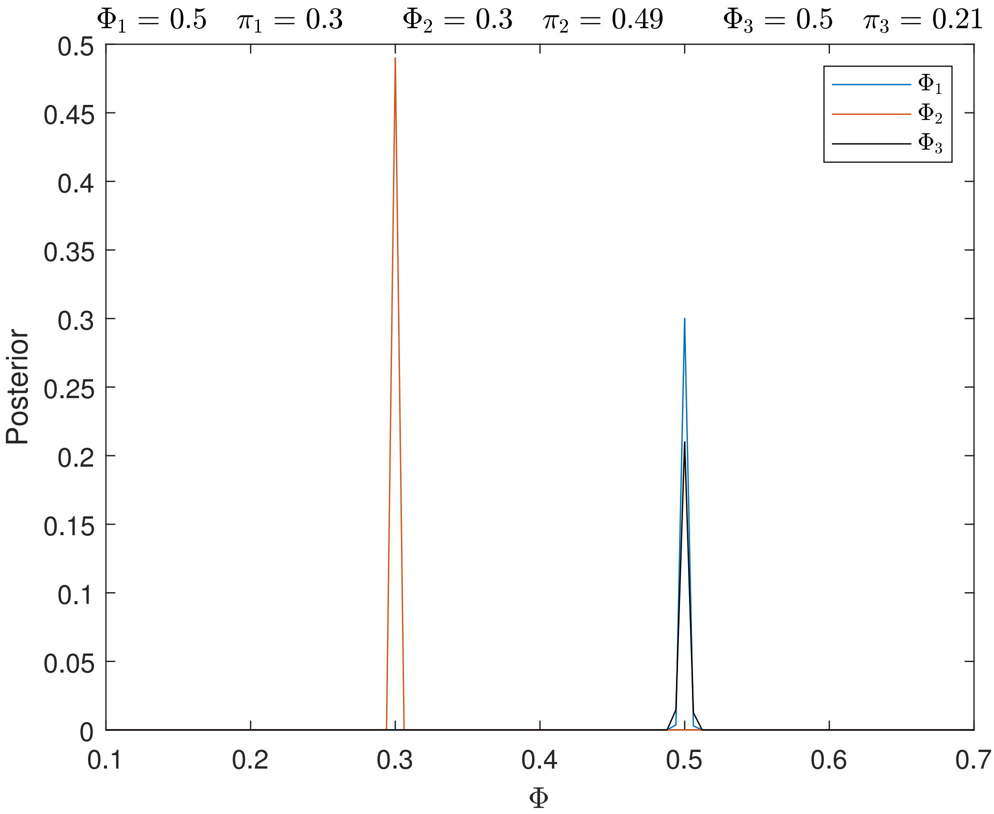


Figure 5.4

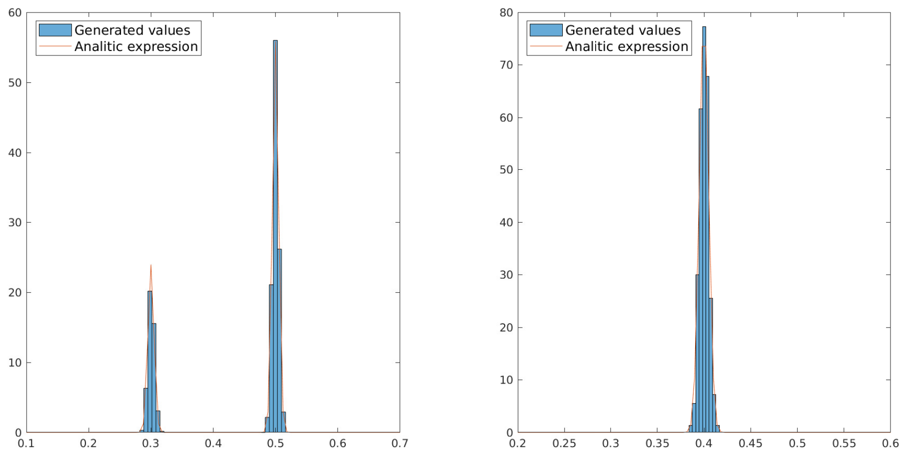


Figure 5.5

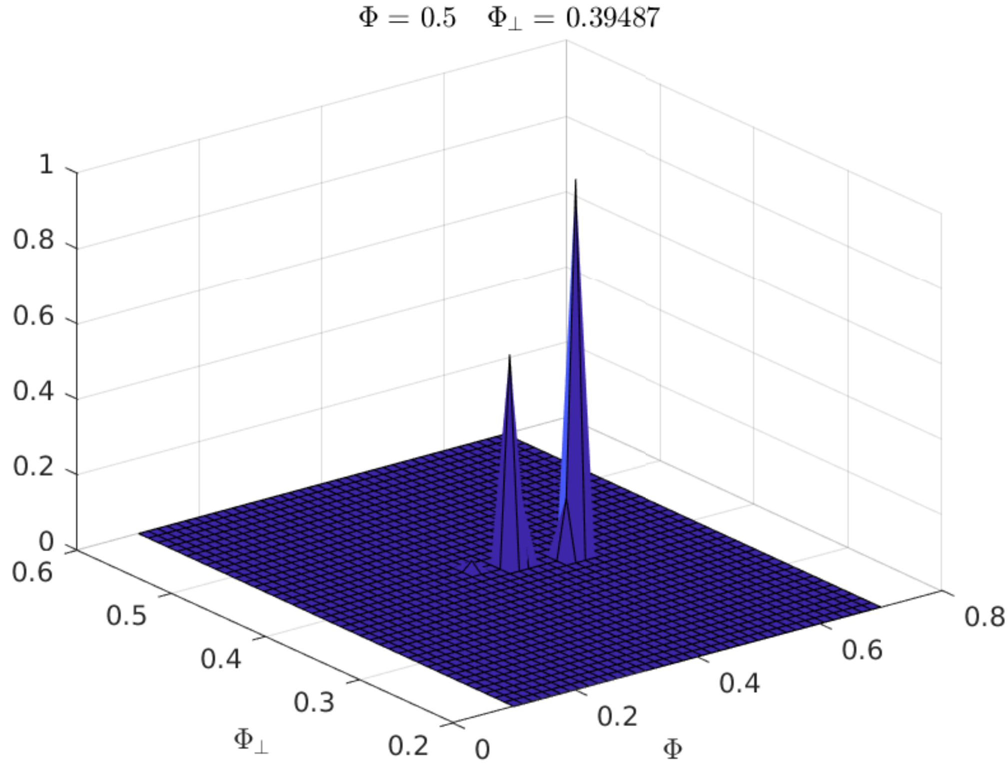


Figure 5.6

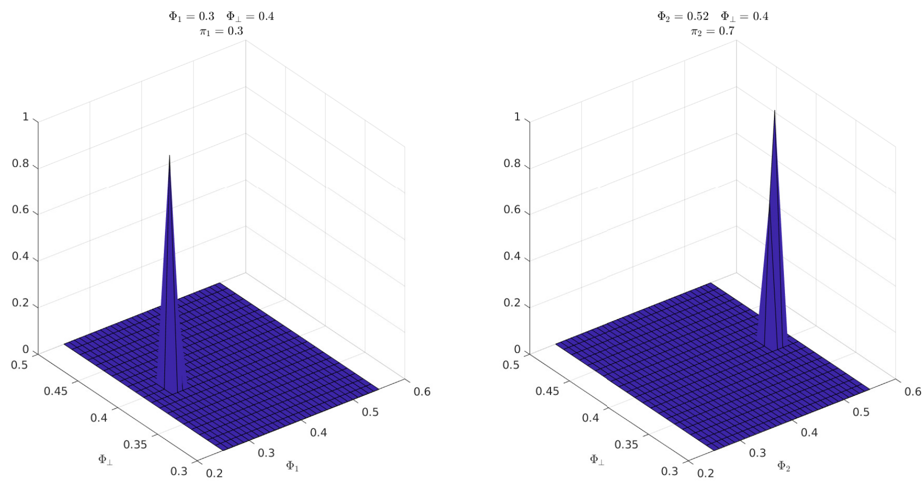


Figure 5.7

Chapter 6

Integration to PoliMIce (To Do)

Implementation of the chosen formula for the c_D in PoliDrop

6.1 Cloud generation

Some rules to generate the cloud by PoliDrop

6.2 Results

6.2.1 Let it snow!

Falling snow test case (Check the terminal velocity distribution for validation?)

6.2.2 Blowing snow example

Blowing snow test case: ice accretion on a profile?

Chapter 7

Conclusions and Future developments