Application of Hough Algorithm to Free Drop Analysis of HB Standard Model in a Ludwieg Tube

EunJu Kim [1], Soo Hyung Park [2] Yung Hwan Byun [3]

Abstract

Determining the attitude angle of an aircraft can greatly help measure the force and moment coefficients without any balance system. There are several ways to measure the force and moment of a model. One of the most representative methods is the use of balance and free-flight module. The method using balance has the disadvantage of having to build an additional DAQ system to receive data. In addition, a deconvolution process that separates the signal from the model due to the vibration of the support is essential. For the free-flight experiment, optical equipment for shadow graph techniques and high-speed camera are required, but force and moment measurements are possible without deconvolution process. The previous study of experimenting with existing free-flight modules included counting pixels on direct images and using Harrison detector algorithm [1] to read and track down points in the model.

In this study, we chose to read straight lines in the model, unlike the image processing method of the preceding study. The algorithm used to read the straight lines on the image is the Hough algorithm. Applying this algorithm in conjunction with the image processing technique allows the recognition of straight lines of falling objects.

Keywords : *Hough Algorithm, Force and Moment , 3-DOF, Free Drop, HB standard model*

Nomenclature

p_0 – Pressure in a storage tube
T_0 – Temperature in a storage tube
M_∞ – Mach number of free stream
p_∞ – Pressure of free stream
u_∞ – Velocity of free stream
ρ_∞ – Density of free stream
T_∞ – Temperature of free stream
C_L – Lift Coefficient
C_D – Drag Coefficient
C_m – Moment Coefficient

1. Introduction

Over the years, there has been a growing interest in the aerodynamic coefficient of the aircraft. Aerodynamics coefficients play an important role in determining the flight path and target range of the aircraft [2,3]. Prediction of these aerodynamics coefficients can be made through experiments, analytical solution of Computational Fluid Dynamics (CFD). In this study, experimental investigations are presented of the HB-2 (Hyper Ballistic - 2) model. A series of free drop experiments of a HB-2 model were performed in the Konkuk University Ludwieg Tube (KULT). Straight line and both endpoints of the model are detected through the Hough Algorithm. Angular velocity and x,y direction velocity can be obtained through the detected straight line and both endpoints. Aerodynamics coefficients C_L, C_D, C_m were predicted by updating 3-DOF (Degree of Freedom) with the values obtained through Hough Algorithm.

2. Experimental details

2.1. Facility and test condition

The free drop experiments were performed in the KULT [4,5]. Ludwieg tube is an experimental device that enables to perform high Reynolds number experiments with its long runtime in relatively low

[1] *Dept. of aerospace information engineering, Konkuk University, seoul korea, julie6045@naver.com*
[2] *Dept. of aerospace information engineering, Konkuk University, seoul korea, pish@konkuk.ac.kr*
[3] *Dept. of aerospace information engineering, Konkuk University, seoul korea, yhbyun@konkuk.ac.kr*

turbulence environments. Konkuk University has designed and validated KULT that can simulate flow conditions from 10km to 23km. The biggest advantage of the Ludwieg tube is its long runtime (80ms for KULT). Since it has long runtime, it is suitable for free drop experiment. Fig. 1 Shows a rendering image of the facility. A Mach 4 nozzle having an exit-to-throat ratio of 12.2 was installed. The nozzle diameter was 100 mm. Table 1 and Table 2 lists the gas flow properties for the present experiments.

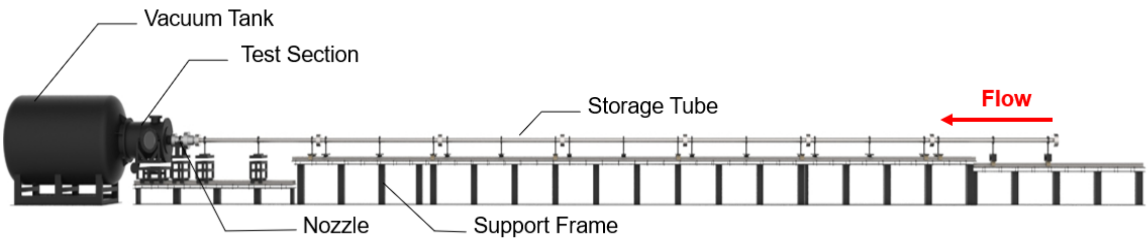


Fig. 1 Konkuk University Ludwieg Tube (KULT)

Table 1. Test flow condition (Storage Tube) [4]

Property	Measurement
$p_0(MPa)$	3 ± 0.6
$T_0(K)$	301 ± 3

Table 2. Test flow condition (Nozzle Exit) [4]

Property	Calculation	
	Analytic	CFD
$M_\infty(-)$	4.0	3.94
$p_\infty(kPa)$	15.9	16.0
$u_\infty(m/s)$	659	661
$\rho_\infty(kg/m^3)$	0.822	0.779
$T_\infty(K)$	71.4	67.6

2.2. Test Model

In this study, experimental investigations are presented of the HB-2 model. HB-2 model is known as the reference wind tunnel model. It is used both to validate wind tunnels and as test cases for CFD tools. Many preceding studies have been conducted on the HB-2 model [6,7]. It is the first attempt to predict the aerodynamic coefficient using Hough Algorithm in KULT. Therefore, the HB-2 model, in which many previous studies have been conducted, was selected to examine whether the Hough algorithm accurately predicts the aerodynamics coefficients.

HB-2 consists of a blunt cone cylinder with a flare. The half-angle of the blunt cone is 25 degrees and junctures have smooth radius fairings. Flare is included to provide a less sensitive model for viscous effects. Fig.2 Shows theoretical geometry of the HB-2 model [8]. In this study, a model with a radius of 10mm has been designed. In the case of free drop experiment, a stable model is required. Therefore, it was intended that center of gravity was located in the front rather than center of pressure. For this reason, the inside of the bottom surface of the HB-2 was dug out and designed as shown in Fig. 3.

A string method of mounting HB-2 in the test section was utilized. This method (see Fig. 4 for a method of suspending the model from the string of the test section using thin wires) can release the test model during the start-up periods of the test flow. The model was suspended from the test section roof using thin wires with liquid glue.

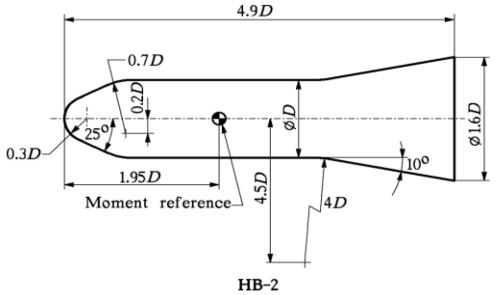


Fig. 2 Theoretical geometry of the HB-2 model [8]

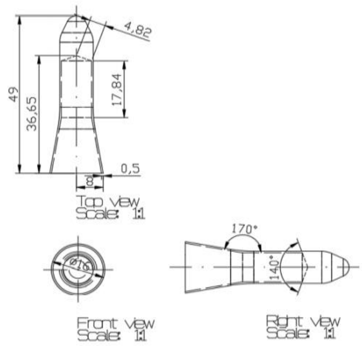


Fig. 3 HB-2 Model with a radius of 10mm

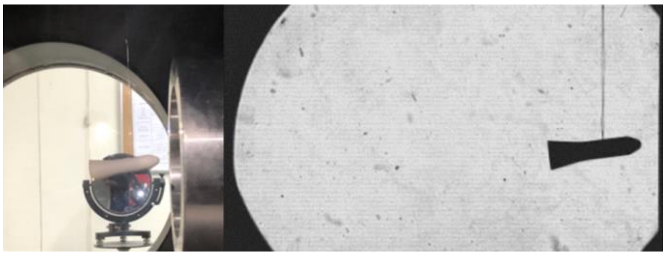


Fig. 4 String method of mounting HB-2

2.3. Image Tracking Technique

The tracking technique consists of a Hough Algorithm. Hough algorithm is an algorithm that enables the detection of lines in image. In this study, it was implemented using MATLAB [9]. For MATLAB, image is recognized as an array. If the y-axis and the straight line on the image are parallel, the slope m is infinite. When an infinite number of elements enter the array, the code will not work, which causes the error. Therefore, the process of removing infinite inclinations is necessary. Hough space is a hypothetical space created to finite the infinite slope which can be represented as in Fig. 5. In Hough Space, the intersection of each line means a straight line connecting each point in the image space.

The present implementation was verified by detecting a straight line above the shadowgraph image of the free flight experimental model (Fig. 6).

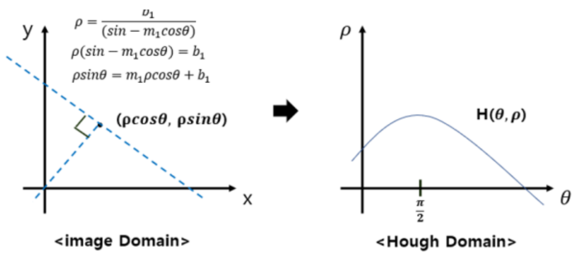


Fig. 5 Image domain and Hough domain

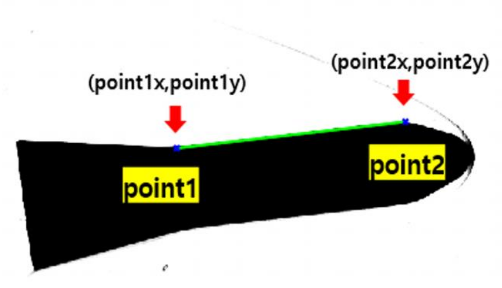


Fig. 6 Detection of Straight line of HB-2

3. Results

Fig. 7-9 shows aerodynamics coefficients of the HB-2 model. In this study, experimental value was compared with the CFD value. It can be confirmed that the experimental value starts at around 6 degrees, proceeds toward the negative AOA, and returns to the positive AOA around 20 degrees. Therefore, it can be seen that the experimental value has the form of a hysteresis loop. Hysteresis loops appear when the state of the model changes. Experimental values draw a hysteresis loop in a counterclockwise direction.

Counterclockwise rotation refers to the movement of the model by the flow, which shows that the model consumes dynamic energy and has dynamic stability. Unlike the experimental value moving, CFD value appears in line pattern. It is caused by the difference between the static CFD value and dynamic experimental value. In the case of C_L and C_D, which are aerodynamic coefficients greatly affected by viscosity, it could be confirmed that the tendency is the same as the CFD, but the value is different. In comparison, it can be seen that the value C_m came out very similar to the value of CFD.

The aerodynamic coefficient of the HB-2 model obtained through free drop must be separated with static and dynamic combined. Therefore, a study of separating into static and dynamic coefficients will be conducted later.

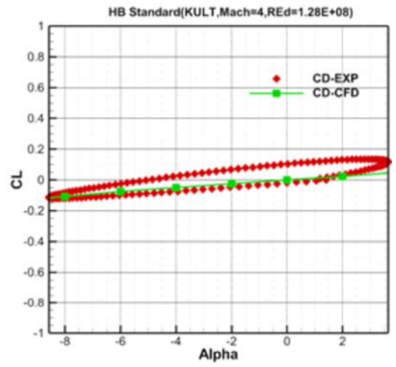
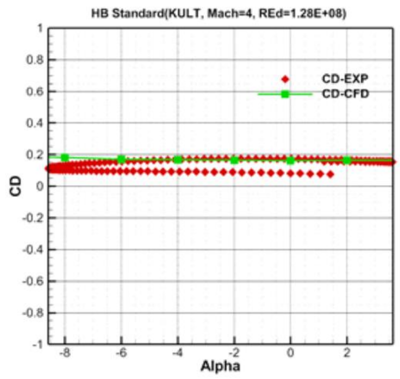


Fig. 9 Lift Coefficient of the HB-2 model



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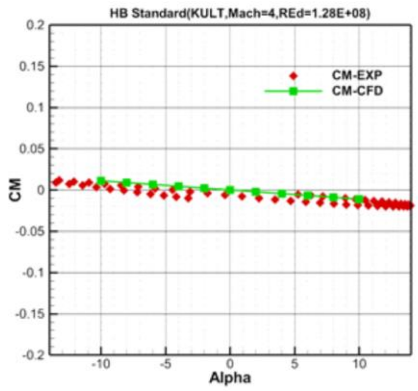

Fig. 9 Lift Coefficient of the HB-2 model

4. Conclusion

In this study, the Hough algorithm was implemented as MATLAB. It was successful to read a straight line and its end points in the model of free drop.

Aerodynamic coefficient obtained through Hough algorithm was compare with the CFD value, and it was confirmed that the tendency was consistent.

Using the Hough algorithm is valuable because it is possible to measure the aerodynamics coefficients of the model only by image analysis without need DAQ system. It is also meaningful that we can address the support-sting configuration issue, which has been the biggest issue in existing HB-2 model experiments.

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