Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 7 Issue 9, September - 2020

Numerical Simulations and Drag Prediction for Base Bleed Projectile

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***Abstract*—base bleed is a common technique that is adopted to reduce drag on projectiles. The degree of drag reduction can be estimated either by expensive live firings or through numerical simulation and engineering techniques. In this paper, drag of 155mm K307 projectile is calculated with dummy and live base bleed units in two approaches. Both 2-D numerical simulations and engineering calculations using PRODAS software are implemented. Results of both approaches are assessed by comparing them with published experimental results for 155mm K307 projectiles with live/dummy base bleed units. Differences between the drag coefficients calculated from numerical simulations and published for are less than 5.4% and 10.6% for projectile with dummy and live BB, respectively. In addition, the maximum deviation between the published measurements and the predicted drag coefficients via PRODAS for the projectile with dummy base bleed is about 4.75%.**

Keywords—computational; 155mm K307, base bleed; drag reduction; aerodynamics; CFD; PRODAS; fluent

I. INTRODUCTION

Extending range of artillery projectiles is the major concern of weapon and ammunition designers. Many factors affect the range of artillery projectiles, some of which are related to the weapon and others to the projectile itself [1]. Drag reduction is considered one of the reliable and economical methods to extend the range of an artillery projectile. The base drag is recognized as a major portion of the projectile total drag at supersonic speeds [2]. Therefore, reduction of base drag is an effective method to gain better ballistic performance. Drag reduction methods should be carefully applied to the projectile in order not to adversely affect its stability during flight. Base drag coefficient can be generally expressed as [3];

$$C_{D_B} = \frac{2(1-\frac{P_B}{P_\infty})}{KM^2} \qquad (1)$$

Where P_B and P_∞ are the absolute pressure of air at base and at freestream, respectively. M and K are the Mach number and air specific heat ratio, respectively. Clearly, for given flight conditions, base drag can be reduce by increasing pressure at base(P_B).

Different methods have been followed to reduce the base drag during projectile flight on its trajectory [4]. These methods are divided into two main groups. The first group of base drag reduction is the boattailing. Whereas; the second group is dependent of base pressure increase.

The second group of base drag reduction methods is to increase the base pressure using active and passive devices. The passive devices have different techniques to increase the pressure behind the projectile base. Some researchers concerned with the base and ventilated cavities techniques [5-8], the multistep base configuration is another technique of the passive devices that is investigated by the other researchers [7, 9, 10]. The drag reduction obtained from using passive devices not exceeded about 20%.

The active devices are divided into two methods; they are base burning and external burning, respectively. Many researchers are investigated the external burning [11-14], other researchers are worked on a combination between external base burning and base bleed [15].

The other method is using a base bleed unit [16, 17], Fig. 1 displays a schematic diagram of the flow past a projectile provided with base bleed unit [18]. It is seen from the figure that the position of primary recirculation region (PRR) shifts downstream due to the injected gases from the orifice of base bleed while a part of the gases escape from bleeding section creating the so-called Second Recirculation Region (SRR). The base pressure behind the projectile increases due to the mass added from the gases injected from the base bleed. Generally, the drag reduction resulting from applying active device, such as a base bleed method is a significant compared with that of other methods of drag reduction, the drag reduction achieved from using base bleed is from 30% to 35%.

Drag can be estimated via three different approaches namely, experimental (wind tunnels and live firing), computational (CFD simulations), or using engineering tools. Nevertheless, live firing results are considered the benchmark values to which results of all other techniques are validated.

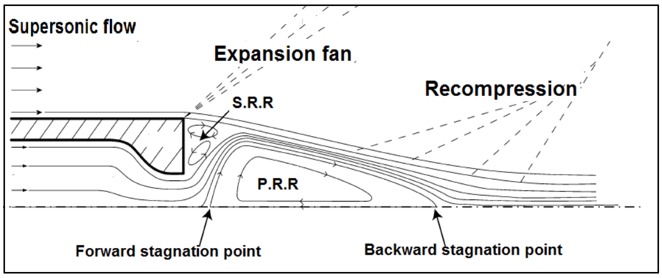


Fig. 1 Schematic diagram of the flow past a blunt base provided with base bleed unit [18].

The present study is conducted on a 155mm projectile with base bleed model K307. The objective is to assess the validity of two techniques in predicting drag namely, numerical simulation and PRODAS V3.5 engineering calculation against available published firing results on the same projectile with dummy/live base bleed unit. Based on the results obtained from this study, reliability of computational approach is assessed for further activities within the running research. In addition, the study makes use of flow visualization capabilities of numerical simulation technique to explore the flowfield features at the base of the projectile for both dummy and live cases.

The remainder of the present paper is organized as follows. Details of computational analysis are explained next followed by a presentation of results and discussed, and the paper finalized with the main conclusions and recommendations.

II. Computational Analysis

A. *Test Cases*

In this study, the 155mm K307 projectile with base bleed is studied, it is widely used in many army forces of different countries, as seen in Fig. 2. This projectile is formed from three main parts; ogival nose, cylindrical midsection, and boattail part. The base bleed grain is placed inside the boattail part and has an igniter inside it to ensure the full ignition of the grain after the projectile leaved the gun barrel.

fig. 3 (i) shows the relative dimensions of the used projectile in terms of the caliber; where A=6.14D, B=0.56D, C=3.66D, E=0.945D, R=31.2D and F=0.285D.

The base bleed container contain the base bleed grain and connected with the whole projectile through a thread, fig. 3 (ii) shows a 3D model for the container to display the central orifice which the hot gases generated from the ignition of base bleed grain exits from it during the projectile flight.

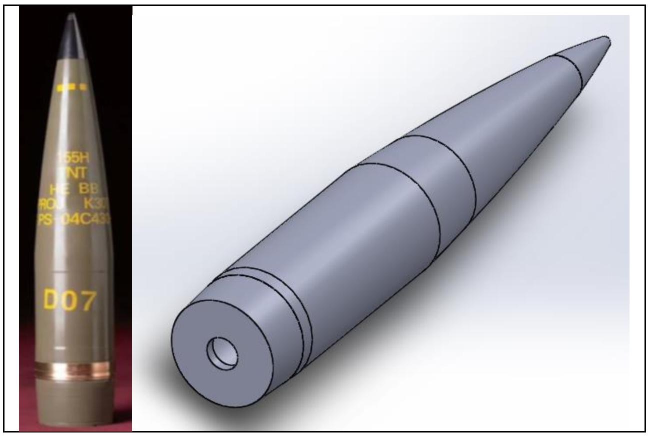
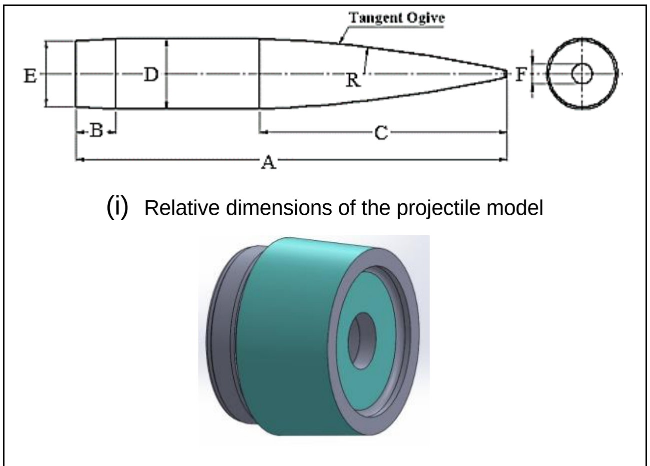


Fig. 2 Real and 3-D model 155mm HEBB K307projectile



(i) Relative dimensions of the projectile model

(ii) 3D model for the base bleed container

fig. 3 Geometrical details of the testing models M1 and M2

B. *Numerical Method*

The present CFD study adopts a commercial computational code, FLUENT14.5 [19], to estimate the drag coefficient on the 155mm projectile models K307 at zero incidence and different freestream Mach number values. The implicit pressure-based scheme is used to solve the system of differential equations. The second order upwind Green-Gauss node-based scheme is also used in discretizing the spatial dependent variables in RANS equations. Coupled scheme is applied for pressure-velocity coupling. The turbulent model used in this work is K-epsilon Realizable Enhanced Wall Treatment. Air as an ideal gas is used as the working fluid for free stream flow. For base bleed gas flow, combustion products of base bleed charge are defined with chemical reaction enabled [20].

C. *Computational Grids and Analysis*

The grid is generated in half of the computational domain since the projectile is an axisymmetric body of revolution and zero-incidence freestream. The grid consists of structured quadrilateral cells as shown in Fig. 4.

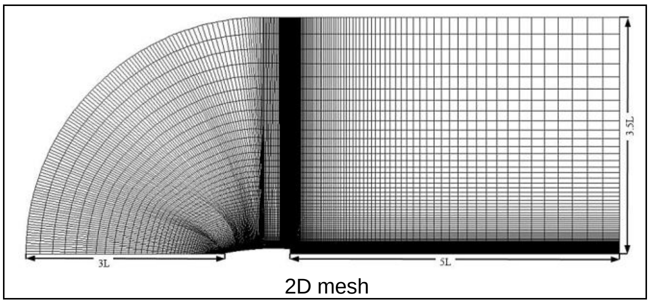


Fig. 4 The structured 2D mesh used in the study

The domain is extended in upstream, lateral and downstream direction up to 3L, 3.5L and 5L, respectively; where L is the projectile length. The pressure far field boundary is set to the uniform upstream flow with defined static pressure and Mach number. The conditions the mass flow inlet of base bleed gases depend on the time and the position of the projectile along its trajectory [21]. Standard atmospheric values pressure is set at sea-level. The symmetric boundary is applied to the line coincident with the projectile axis. The adiabatic no slip conditions are set to the solid projectile surfaces.

Six 2-D version of the structured grids Grid with different resolutions used in sensitivity study, the studied grids varying from 54300 cells to 85000 cells. Fig. 5 shows the evolution of drag coefficient on the projectile unit grid size normalized by the size of the course one. The free stream for grid sensitivity check corresponds to Mach 1.5.

A grid with 72300 cells is adopted since no significant improvement is attained with further increase in cell counts. This grid has 280 cells was distributed around the body (115 on ogive, 30 on cylindrical body, 50 on boattail and 85 on base), with about 140 cells upstream and above the model length and 200 cells downstream.

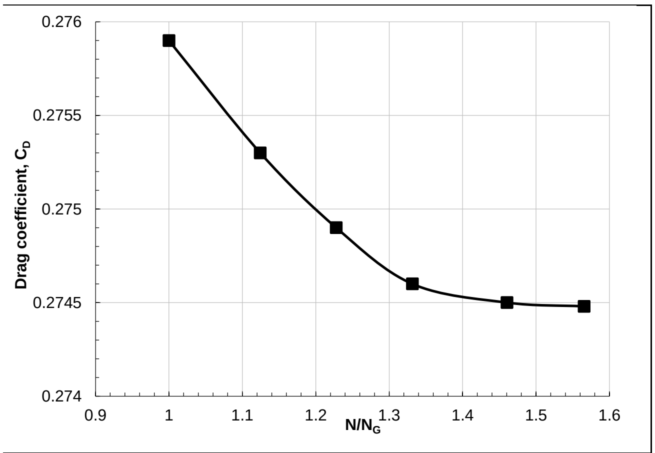


Fig. 5 Drag coefficient of inert projectile versus normalized number of cells at M=1.5.

D. *PRODAS V3.5 Software*

PRODAS (Projectile Rocket Ordnance Design and Analysis System) is basically a design tool of semi-empirical method developed by Arrow Tech Associates Inc. It has been developed using proven methodologies and techniques such that predicted performance estimates are based on prior experimental testing [22]. PRODAS very quickly obtains the aerodynamic coefficients with a given axisymmetric geometry and flow conditions.

III. Results and Discussion

A. *The published live firing experiments measurements*

Hwang and Kim [23] performed a firing experiments of 155mm K307 projectiles with dummy/live base bleed. In these measurements, a 155mm/52 calibre howitzer gun was used, the elevation and muzzle velocity are kept constant at 50 degree and at 900 m/sec. The bleeding exit in used projectile was central orifice with a diameter of 44mm. Their tested results showed that maximum range of 155mm K307 projectile with dummy and live base bleed was 31.5 km and 41 k, respectively.

Fig. 6 shows the measured drag coefficients of the fired 155mm K307 projectiles with dummy/live base bleed.

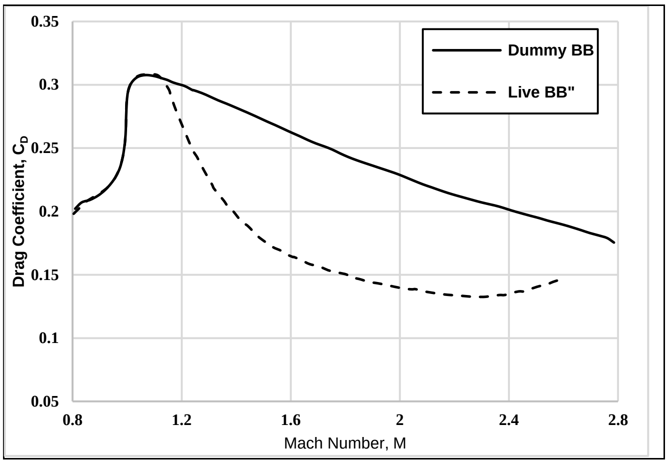


Fig. 6 Drag coefficients versus Mach numbers [23]

B. *CFD Validation with Live Firing Results of Ref. [23]*

The experiments of Hwang and Kim [23] are reproduced numerically using axisymmetric computational domain for the range of Mach numbers. Fig. 7 compares the experimental measurements of Ref [23] and computational results of the total drag coefficient at different Mach numbers for projectile K307 with dummy and live base bleed.

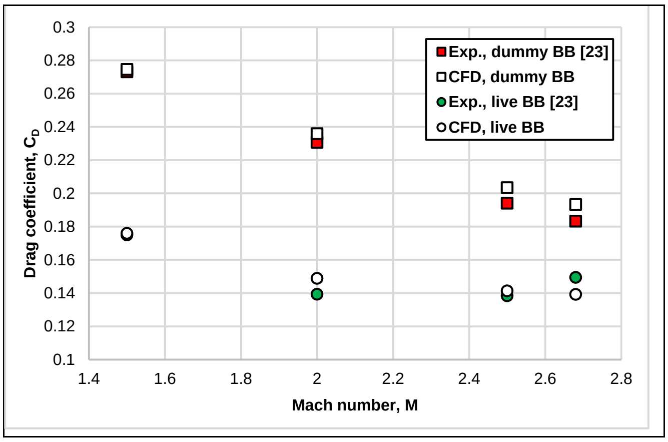


Fig. 7 Experimental and computational values of drag coefficient versus Mach number for K307 with dummy and live BB

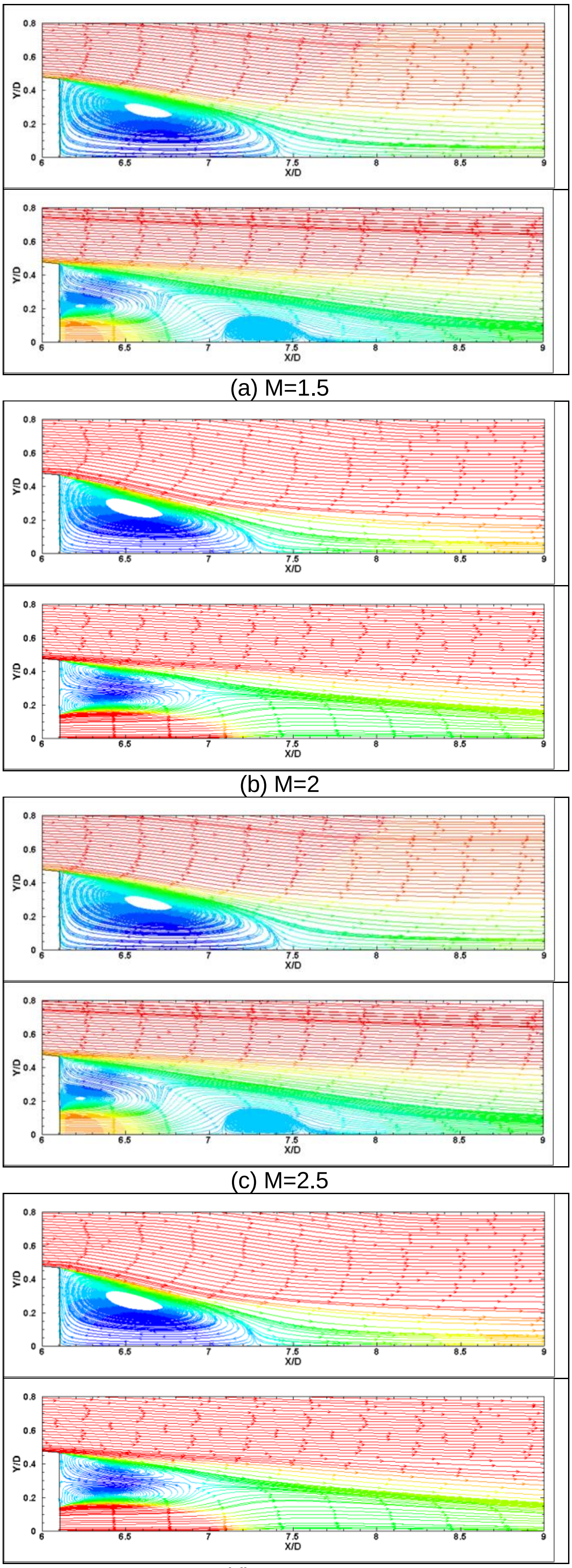
Good agreement is noticed between the 2-D computational results of the total drag coefficients with the experimental measurements of Ref [23] for the total drag coefficient; the maximum absolute difference is found to be 5.4% and 10.6% for dummy and live BB, respectively. This is better illustrated in Table 1.

TABLE 1 EXPERIMENTAL [23] AND COMPUTATIONAL DRAG COEFFICIENTS RESULTS FOR K307 WITH DUMMY AND LIVE BB.

Mach	Dummy BB			Live BB		
	Firing [23]	*CFD (2-D)*	*Maximum absolute difference, (%)*	*Firing [23]*	*CFD (2-D)*	*Maximum absolute difference, (%)*
1.5	0.2731	0.2746	0.5	0.175	0.1825	4.3
2	0.2307	0.2359	2.25	0.1394	0.1542	10.6
2.5	0.1941	0.2035	4.8	0.1384	0.1436	3.75
2.68	0.1833	0.1933	5.4	0.1495	0.1408	5.8

The impact of live BB is clear from the previous figure and table, it can be noticed that the drag reduction is about 18% to 40% when live BB is used. The role of base bleed can be better understood by exploring the flow field features at the base of the projectile. Based on computational reproduction of the work of Hwang and Kim [23].

Fig. 8 shows the contours of velocity at different Mach number for the projectile K307 with dummy and live BB. In case of dummy BB unit, the low pressure recirculation region is created at the projectile base, which is formed due to its separation from external flow by the shear layer to the rear stagnation point. The location of this point shifts from 7 calibers to 7.5 calibers downstream of the base as Mach increases from 1.5 to 2.68 as depicted in fig.10. On the other hand, in case of live BB unit, injected fluid acts on weakening the circulation zone by separating it into more than one zone. The recirculation shifts downstream and reducing the size of circulation.



(a) M=1.5

(b) M=2

(c) M=2.5

(d) M=2.68

Fig. 8 Predicted velocity contours in case of dummy BB (up) and live BB (down) at different Mach numbers

C. Comparison of the predicted results from PRODAS with published firing results for K307 projectiles with dummy base bleed [23]

PRODAS is designed to predict the range and the aerodynamic coefficients of axisymmetric projectiles. However, it is incapable of handling projectiles with live base bleed units. Therefore, to verify the reliability of PRODAS for a good prediction of the range and aerodynamic coefficients, all dimensions and materials for every component of the dummy 155mm K307 projectile is entered in the PRODAS software, as shown in Fig. 9.

Fig. 10 shows a comparison between the experimental measurements [23], computational results and predicted results by using PRODAS for the drag coefficients of 155mm K307 projectile with dummy base bleed.

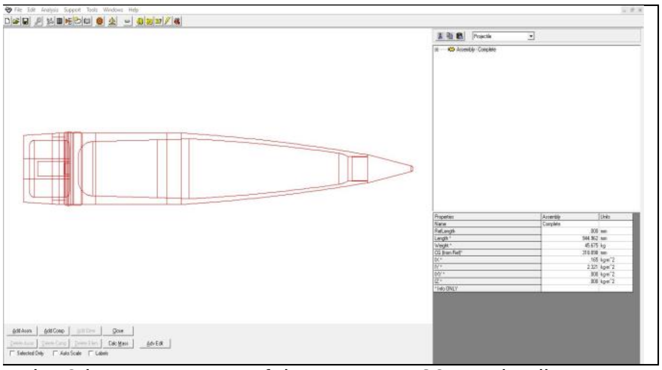


Fig. 9 input geometry of the 155mm K307 projectile

The total drag coefficients of the K307 projectile with dummy base bleed predicted from the PRODAS and measured from the experiments of Ref [23] have a good agreement; the maximum absolute deviation is found to be 4.75% at Mach number 2.68. The values of predicted and measured total drag coefficients for the projectile model K307 with dummy base bleed are listed in Table 2.

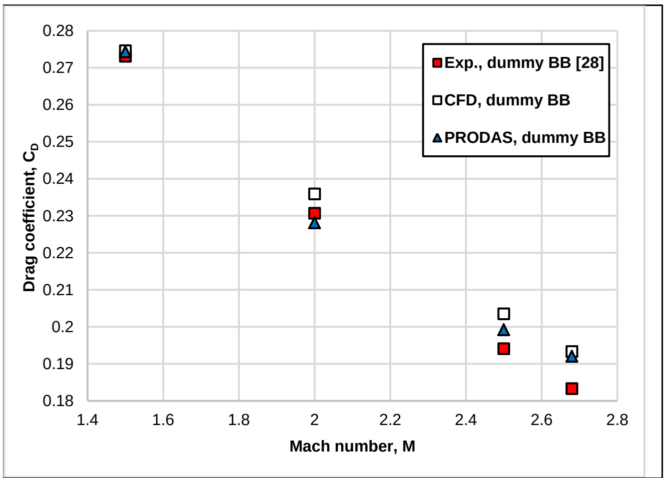


Fig. 10 Experimental, CFD and predicted by PRODAS values of drag coefficient versus Mach number for K307 with dummy BB.

TABLE 2 EXPERIMENTAL [23] AND PREDICTED BY PRODAS DRAG COEFFICIENTS RESULTS FOR K307 WITH DUMMY BB

Mach	Dummy BB		
	Firing [23]	*PRODAS*	*Maximum absolute difference, (%)*
1.5	0.2731	0.2743	0.4
2	0.2307	0.2281	1.1
2.5	0.1941	0.1992	2.6
2.68	0.1833	0.192	4.75

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

- Validation of 2-D numerical simulations has been done with published results of live firing experiments of 155mm K307 projectiles with dummy/live BB. The computational results capture the exact trend of the published experimental measurements of the total drag coefficient and the maximum absolute deviations were less than 5.4% and 10.6%, respectively. The relatively large deviations in the live base bleed case invoke further investigation however, burn pattern of base bleed unit may be a primary cause.
- A noticeable decrease in drag is achieved when live BB is used instead of dummy BB, the drag reduction was about 18% to 40% depending on Mach number.
- PRODAS is a reliable software that has a fair prediction accuracy of the drag coefficients of an axisymmetric projectiles. The maximum absolute difference of total drag coefficients between the experimental measured and the results obtained from the simulation and PRODAS for 155mm K307projectile with dummy base bleed are 5.4% and 4.75, respectively.

B. Recommendations

- A 3-D computational simulations should be performed for the studied projectile model K307 with base bleed to have an accurate results for drag coefficients.
- The angle of attack should be taken into consideration in the future work to investigate its effect on the total drag coefficients.
- PRODAS should be used as a fastest predictor of the aerodynamic coefficients and all trajectory data by one click the solution appears in no time. The good prediction of PRODAS can saves a lot of money and efforts.

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