Meteorological Wind Effect on the Ballistic Trajectory of a Medium Calibre System

Abstract

Current Armoured Fighting Vehicle (AFV) Fire Control Computer (FCC) systems use a single onboard meteorological sensor to measure wind vector conditions in order to calculate wind offset corrections within FCC ballistic trajectory algorithms. This project was undertaken to explore whether multiple sensors placed along the trajectory path could be added into the ballistic solution to potentially provide a more reliable and accurate algorithm.

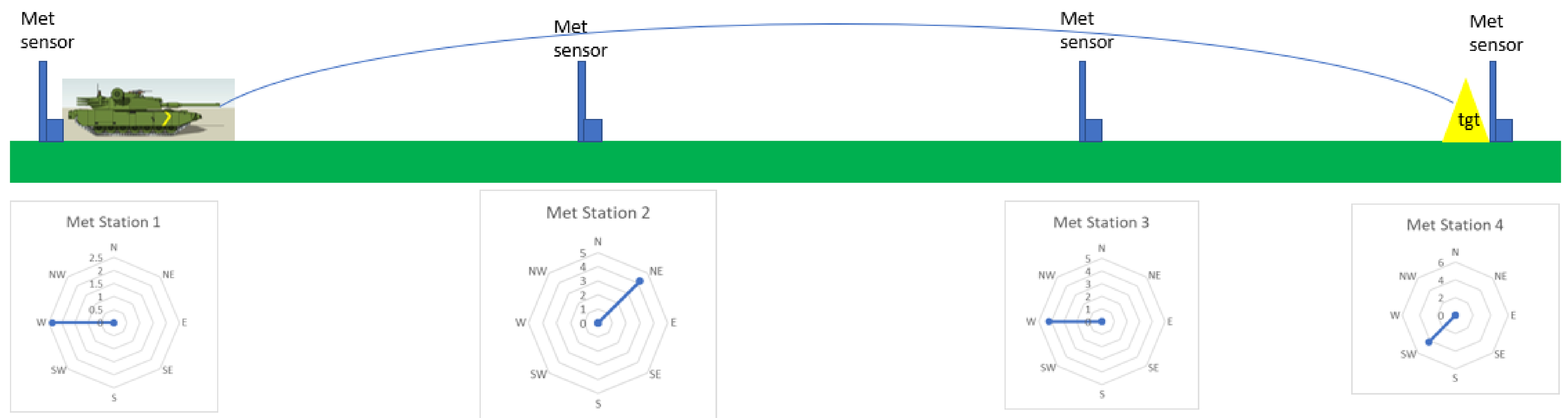

Figure 1 – Range Template Meteorological Wind Station Set up (3)

Method

On a fully instrumented firing range, meteorological wind sensors were placed along the length of the expected trajectory. Each sensor captured wind speed and direction at its location and reported back to the master station 1 at the firing point, which also captured air temperature and air pressure. Figure 1 shows an example layout of the sensors.

The meteorological data captured was analysed in two ways;

1) The instantaneous metrological wind effects on the ballistic trajectory at the point of firing.
2) Characteristic averaged overview of the local environmental conditions that influenced the projectile flight and the winds stability from changing gustiness.

The resultant instant and averaged wind profile data was then input into the McCoy Flat Fire ballistic trajectory model (1) (shown below) to produce the resultant trajectory plots shown. Additionally a Point Mass NATO model (2) was also used but not presented here.

Table 1 – Test Station data

Data Sets	Station 1 0 km Direction Wind Speed	Station 2 1 km Direction Wind Speed	Station 3 2 km Direction Wind Speed	Station 4 3 km Direction Wind Speed	Notes
Z2	West 1.89 ms^{-1}				Constant
Z5	West 1.89 ms^{-1}	West 1.89 ms^{-1}	West 1.89 ms^{-1}	West 1.89 ms^{-1}	Weighted steps - constant
Z6	West 1.89 ms^{-1}	West 2.23 ms^{-1}	West 2.55 ms^{-1}	West 2.55 ms^{-1}	Weighted steps

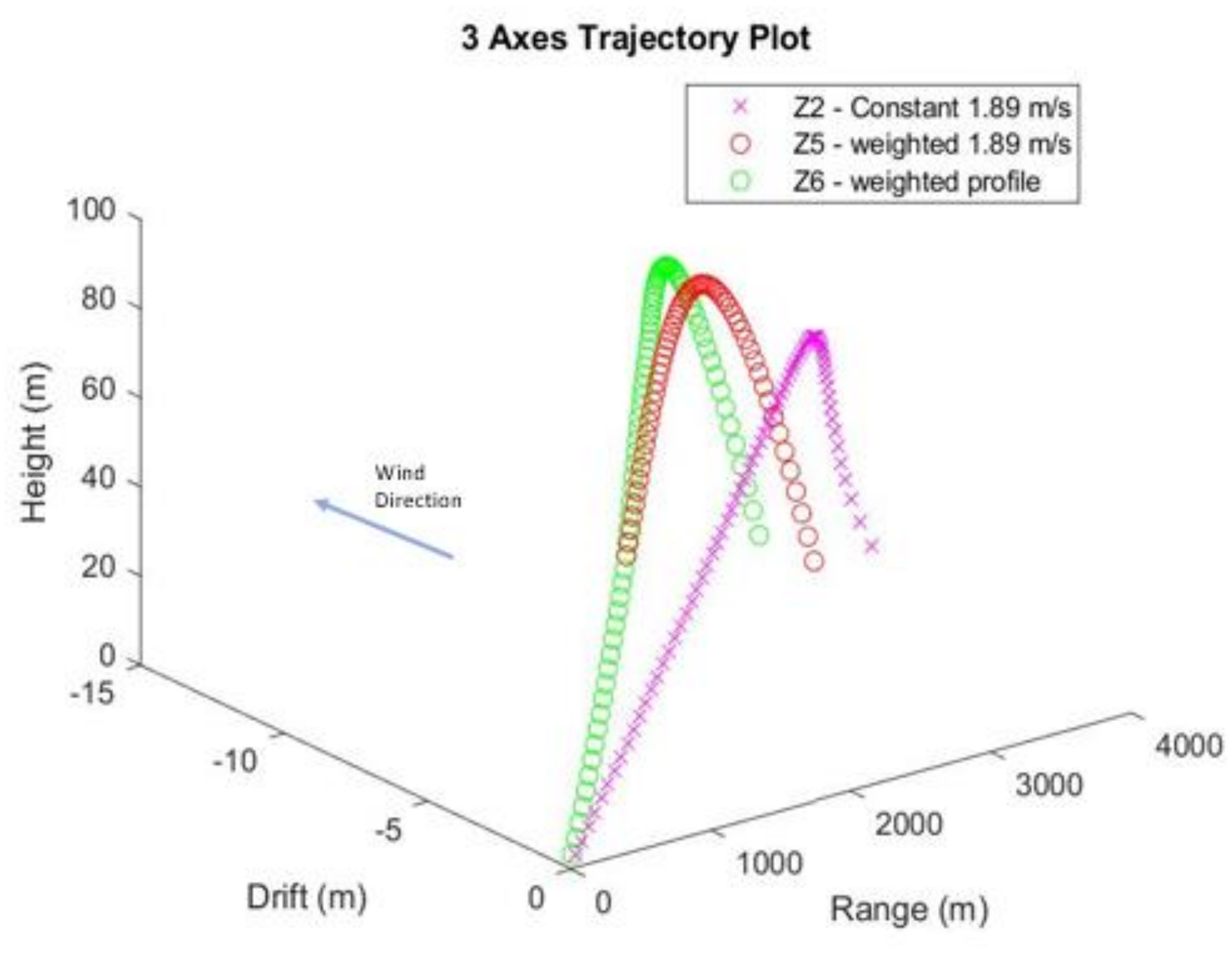

Figure 2 – 3 Axis Trajectory Comparison

Discussion

Trajectory drift has three main components; Coriolis drift from the earths gravity; Wind drift offset and finally the gyroscopic drift from the projectiles rotational speed.

$$Drift_z = Coriolis_z + Wind_z + gyroscopic_z$$

Under current AFV FCC calculations, the constant wind offset component used within the above equation to understand full trajectory range drift is presented as follows, the graph results are shown in Z2 (pink) output:

$$Wind\ Drift_{Constant} = Crosswind_{Speed}\left(FlightTime - \left(\frac{Range_{Final}}{Initial\ Velocity}\right)\right)$$

This research provided the opportunity to investigate variable (down range) wind drift, from multiple sensors, which therefore used the weighted wind equation as follows:

$$Wind\ Drift_{Weighted} = \sum\left(Crosswind_{Speed}\left(Flight\ Time_{Range} - Flight\ Time_{Range\ Step} - \left(\frac{Range_{Final} - Range_{Step}}{Velocity_{Step}}\right)\right)\right)$$

This equation takes the wind speed input at multiple points (e.g. 1000 metre steps) along the trajectory and then sums the overall wind offset together that influences the projectile drift. This example of variable meteorological wind is shown in data set Z6 in the graph.

To accurately assist in comparing the two concepts a third test set, using identical wind reading at every step in the weighted equation was used to simulate a constant wind. This data set Z5 shows a smoother profile compared to the Z2 equation profile.

Another component to the wind equations which is commonly missed out but, was included in these tests, is the wind gradient equation. This takes the crosswind speed at the sensor height ($height_{ref}$) and adjusts the wind speed as the trajectory increases in height using an environment roughness exponent, (a) seen below. This exponent is found by analysing the overall wind average characteristic profile which determines the stability of the wind environment, i.e. unstable 0.34 and stable 0.10 exponent value.

$$wind\ speed_{real} = wind\ speed_{ref}\left(\frac{Round\ Height}{Height_{ref}}\right)^a$$

Metrological wind drift is known to be the largest source of drift and confidence error in the ballistic algorithm, which can be seen from the data presented. The smallest change in wind speed can affect the offset of the trajectory to the target. For example if we assume that the projectile trajectory due to real wind drift is the Z6 data, then the Z5 constant wind weighted equation results are closer and present a smoother profile compared to the Z2 results. This approach could improve the ballistic algorithm, justifying further investigation into the equation difference and the multiple sensor difference on the resultant trajectory.

Conclusions

- Comparison of the results from the single sensor vs multiple sensors shows a significant difference in the resultant trajectory and shows the potential for refinement in the wind drift error.
- Applying constant wind into the weighted equation (Z5) shows a delta to the wind drift error compared to the constant equation (Z2), assuming (Z6) results are what you actually get from down range meteorological wind drift.
- Examination of overall environmental meteorological wind data shows that the wind conditions are unstable and gusty. The roughness factor is then a valid component to be included within the ballistic calculations.
- If we can take all these points into account, there is the possibility of reducing the delta error between FCC offset and true flight of projectile and increasing the confidence of first time hit.

Recommendations

- Understanding the environmental characteristics of meteorological wind stability and its gustiness along the trajectory, to determine the influence on first time hit confidence.
- Validating the effectiveness of a single sensor compared to a multiple sensors approach to ballistic correction will require empirical testing in a controlled environment.
- Finally the development of tactical battlefield options to incorporate additional sensors such as offboard drones, sensor networks and onboard far-range wind speed doppler radar units, that are in current development.

Reference

(1) McCoy, R. L. (2012) *Modern Exterior Ballistics The Launch and Flight Dynamics of Symmetric Projectiles*. 2nd edn. Schiffer Military History
(2) NATO Standardization Agency (2009) *STANAG 4355; The Modified Point Mass and Five Degrees of Freedom Trajectory Models*. 3rd edn. Brussels: NATO Standardization Agency
(3) Dedoimedo.com. (2019). A main battle tank – The finest 3D model ever!. [online] Available at: https://www.dedoimedo.com/art_3d/tank.html [Accessed 26 Sep. 2019]

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MSc by Research 2019 - 2021

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