Title: Preliminary Aeromechanical Design of Sub-Guided Munition for Artillery Rockets

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A novel concept has been developed to improve the capabilities of MLRS, by the development of a sub-guided munition for surface-to-surface unguided rockets. The sub-munition designed not only the precision of fires by using low cost GPS/INS guidance but also provides a dramatic increase of the operative range of this kind of weapons. This paper presents the aeromechanical efforts done in the system concept development.

Introduction: Currently many unguided rocket artillery systems are being improved by including correction trajectory modules in order to reduce ballistic errors, in other cases precision guidance and navigation kits are being fitted to existing unguided artillery rockets. Several means to generate control forces to steer the rockets were developed, including canards fins with free rolling motion, canards fins in forward modules decoupled from the main rocket body to avoid unwanted roll responses, lateral thrusters located in the nose or close to the center of gravity of the rocket, etc. In all the mentioned cases, the control system are capable to cope with ballistic errors as well as to generate correction forces demanded by precision guidance but in most cases the maximum range is not increase substantially. In general the correction kits for artillery rocket could be classified as low-g maneuver systems. On the other hand some of the mentioned systems are not always able to generate trajectory shaping in the latest portion of the trajectory or they have reduced capability for maneuver for the end-game. Trajectory shaping in the end game could be an important contribution to increase the weapon effectiveness against some specific targets, including vertical attack for hard targets, improvement of fragmentation effects due to larger trajectory angles at impact, etc. On the other hand the fact that the attacking munition is smaller than the complete rocket increase its survivability against missile defense due to the smaller radar cross section and the possibility to perform random maneuvers during the gliding phase.

A novel concept has been developed has an alternative option to transform unguided low-precision artillery rocket in a precision weapon, using a sub-guided unpowered gliding munition as payload for an artillery rocket. The new generation of 40Km range, 122mm rocket is ideal candidate to incorporate this concept. The guided gliding munition is fixed as warhead. The rocket motor and warhead (with or without guidance) separates at a specific point in the trajectory. This method would extend the range of the rocket by an additional 30Km. the munition would retain enough energy to perform trajectory shaping at the end game as well as random maneuvers during gliding to avoid interception (Fig. 1). This guided munition has been designated as “MUGAP “and it is fitted with an integrated low cost GPS-INS system. The only previous development in a similar concept was tested by Boeing and Saab using existing hardware (MLRS and SDB).

![Fig. 1](image_url)
1. Munition Concept Design and Aeromechanical Requirements Analysis:
The gliding sub-munition concept has been developed based in the following initial requirements and constraints:

- Tail control for pitch and roll
- High L/D ratio
- Maneuver capability required by the defined target basket as well as the end-game trajectory shaping
- Folded wing and control tail surfaces
- Statically stable configurations, body-tail after separation from the carrying rocket and wing-body-tail during gliding and maneuver
- High aspect ratio wing and tail due to the constraints in the munition diameter and wing area required for high L/D
- Roll controlled configuration
- Interdigitated wing-fin arrangement configuration

The initial configuration is displayed in Fig. 2 and the operation concept in Fig. 3. The MUGAP has a total mass of 16 Kg.

![Fig. 2 MUGAP Preliminary Configuration](image)

![Fig. 3 MUGAP Concept](image)

A typical separation conditions from the carrying rocket are as follows

- Altitude: 16000 meters
- Horizontal range at separation: 22000 meters
- Vertical velocity: -20 m/s
- Velocity over the trajectory: 340 m/s, Mach = 1.2
- Roll rate: 6 Hz

Immediately after separation the munition deploys the tail fins, to slow down the roll rate and control it, keeping the munition flying in “+” position and then the wings are deploy, the munition flies with the wings in “x” configuration for gliding and maneuver (Fig. 4).
This paper describes preliminary aeromechanical effort for MUGAP, using several standard computer programs for missile aerodynamics prediction and some software tools developed for this project:

- Missile Datcom
- Modified ADAM-2 computer including fin gap and body slot effects
- Aero Troll – Panel Method
- Engineering code using coefficient synthesis method plus empirical (MUGAP code)
- Vortex Lattice Code AVL + CFD corrections
- Proprietary CFD codes developed in house

The main effort done was to modify the source code of ADAM program in order to include the effect of body slots, fin gaps as well as the lift and drag of high aspect ratio lifting surfaces. These modifications in ADAM are explained in detail in the next section. Preliminary findings shows that a very low angle of attack Missile Datcom and ADAM predicts in similar way both the pitching moment and normal force coefficients, however a larger angles of attack (10 degress) the prediction between the codes divert (Fig. 16a and Fig 16b.), this occur due to several reasons including the effect of body slots and fin gaps as well as the behavior at larger angles of attack for both wings and tail fins which are not “small aspect ratio”. ADAM was modified to deal with wing and tail fin stall which occurs at an angle of attack range lower than for typical missile fins (small aspect ratio) as well for body slot and gaps using an engineering approach developed from experimental and CFD data for lift losses and increase of drag. The main interest was to improve the prediction of Lift/Drag ratio.


The aerodynamic model of ADAM 2 missile engineering code is based on the “coefficient synthesis methodology”. The aero-model valid for tail controls is:

\[
C_N = C_{NB} + C_{NWEX} (K_{WB} + K_{BW}) + C_{NTEX} (K_{TB} + K_{BT}) + C_{NWT} + \Delta C_{NX} \quad (1)
\]

- \(C_{NB}\) = Normal Force body alone
- \(C_{NWEX}\) = Normal Force exposed wing
- \(C_{NTEX}\) = Normal Force exposed tail
- \(C_{NWT}\) = Normal Force due to wing-tail interference (downwash)
- \(\Delta C_{NX}\) = Normal Force component created by the axial force in the case of deflected controls
- \(K_{WB}, K_{BW}, K_{TB}, K_{BT}\) = Slender-body coefficients for body and wing/tail interference.
The aerodynamic coefficients of the individual components for body, wing, and tail are predicted at the effective angle of attack of each component. It is assumed that the angle-of-attack characteristics of the isolated body, wing, tail, flare, and boattail are known up to 25 deg of AoA (Angle of Attack). The effective AoA $\alpha_e$ for each component is obtained as follows ($\alpha=$angle of attack of the undisturbed flow):

\[
\begin{align*}
\alpha_{eB} & = \alpha: \quad \text{AoA for body alone} \\
\alpha_{et} & = \alpha + \alpha_{WT}; \quad \text{AoA for undeflected tails} \\
\alpha_{et} & = \alpha + \alpha_{WT} + \eta(\kappa_{TB} + \kappa_{BT}) / (\kappa_{TB} + \kappa_{BT}); \quad \text{AoA for deflected tails} \\
\alpha_{WT} & ; \quad \text{downwash angle due to the wing-tail interference} \\
K_{WB}, K_{BW}, k_{TB}, k_{BT}; \quad \text{slender-body interference coefficients for the angle of attack and for control deflection cases.}
\end{align*}
\]

The above-mentioned equations are valid for the two horizontal wing and tail panels, assuming that the roll angle $\phi$ is zero (+ position, one pair of panels lie in the horizontal plane). In fact, the code applies Eqs. (1) and (2) separately to each of the four wing and tail panels. In the case of $\phi=45$deg, all four panels contribute to the normal force, thus Eqs. (1) and (2) become far more complex. A similar set of equations exists for the prediction of the pitch-moment and the complete description of the methodology for the prediction of the axial force coefficient is described in Ref. 3. The code estimates the aerodynamic coefficients under consideration at any Mach number for $0>Ma>5$.

The aerodynamic model of ADAM has been modified to cope with configurations having:

- High aspect ratio wing and tail
- Body slots for wing and / or tail
- Gaps between body and control surfaces
- Configurations with multi-fin (6 or 8)
- Increase of axial force due to open slots

The current model of ADAM is limited to low aspect ratio wings and works fairly good for lifting surfaces with aspect ratio up to 3. This limitation of low or medium aspect ratio wings is very common in most missile aerodynamics codes based on engineering methods at least at angles of attack near the wing stall. Even the Missile Datcom which has an specific subroutine to predict wing or tail stall as well as the lift of the wing after stall does not produce in many cases good results for the high aspect ratio wings, mainly at subsonic and transonic speeds.

The proposed modifications are as follows:

\[
\begin{align*}
C_{Nt} & = C_{NB} + FNF_{w}.CNwex. FG_{w}.(K_{WB} + FS_{w}. K_{BW}) + \\
FNF_{t}.C_{NTex}. FG_{t}.(K_{TB} + FS_{t}. K_{BT} + CNWT + \Delta C_{NX})
\end{align*}
\]

Correction factors are applied to the wing or tail lift to take into account the slot and gaps effect and an empirical correlation for wing maximum lift for high aspect ratio wings is used to represent the lifting surface stall and the post-stall lift. The downwash contribution to the tail aerodynamic loading is also modified by the effect of the wing gap and slot. However in the proposed model only wing gap effect has been considered, due to the fact that the slot effect affect mainly the carryover lift onto the body and in most of the engineering models for aerodynamic prediction of missiles, the carryover lift is not included in the estimation of the downwash, this approach is not the same regarding downwash as the proposed by Washington.
FNFw, FNFT: Correction factors multifin from Ref. 15, wing or tail
FGw, FGt: Correction factors gap effect from Ref. 5, wing or tail
FSw, FSt: Correction factors slot effect wing or tail from References 4, 6 and 7

The correction factors for slot effects are valid for 0 and 45 degrees roll angles.

The axial force equation is modified as:

\[ CA = CA \text{ (ADAM2)} + \Delta CA_{\text{slot}} \] (3)

The value of \( \Delta CA_{\text{slot}} \) is obtained from inspection of experimental data and CFD simulations from References 4, 6 and 7. In order to validate the proposed modification of ADAM 2 computer code, the test data of the Copperhead laser guided projectile (Fig. 7) has been selected for test bench 4, 5, 6, 16. The prediction of the Copperhead projectile aerodynamic coefficients using the modified ADAM2 code was done at M=0.5 and roll angle =0. In this validation, comparisons with the prediction with Missile Datcom 2 were included for reference. The data corresponds to the Copperhead configuration with wing and tail slots open.

![Fig. 7 Copperhead Guided Projectile](image)

![Fig. 8 Copperhead Axial Force Coeff. vs. AoA](image)
Figures 8, 9 and 10 shown the comparisons between ADAM 2 (modified), Missile Datcom and test data for the Copperhead projectile. Axial force coefficient is very well predicted by ADAM for slot opens, while the lack of the Missile Datcom to deal with the drag increase due to the slots undepredict the axial force coefficient in the range of interest of the AoA. The normal force coefficient prediction in function of AoA is well predicted by both computer codes, while the pitch moment predictions are similar at low angles of attack, being the ADAM2 prediction a slight better at angles of attack higher of 10 degrees. However the prediction of the maximum Lift/Drag ratio shows that the Missile Datcom overpredict the L/D max by more than 40 %.

**L/D Max – Copperhead**

- ADAM 2 = 3.3
- Missile Datcom = 4.8
- Test Data = 3.2

In this case the results of the test data and prediction done with both codes, regarding normal force and pitching moment shows that the main influence of slots in the aerodynamics of the Copperhead is mainly in the axial force and have less impact on the
lift and static longitudinal stability at least at low angles of attack. As it is documented in references 5 and 16 the gaps effects on the controls have an important impact on the control authority and those effects shall be accounted for.

It is important to remake that the use of standard aerodynamic codes for missiles and projectiles can not be applied directly in the case of slotted projectiles or missiles, because large overestimations of the gliding performances can be obtained.

Another example for validation of the modifications of ADAM 2 was based on the CFD and engineering level aerodynamic analysis of the Slotted Missile from Ref. 7.

In this case the configuration with eight fins as wing arrangement and cruciform tail was analyzed at M= 0.8 and up to 15 degrees of AoA. The results of the prediction of ADAM 2 are compared with the CFD and engineering analysis of Ref. 7 showing a very good agreement between both methods, for axial and normal forces coefficients as well as for the axial force. The multifin correction applied in ADAM 2 for normal force of lifting surfaces seems to be adequate even for this case where the fins aspect ratio is not in the category of "low aspect ratio".
3. Short Description of Ongoing Efforts to Develop Aerodynamic Prediction Tools for Gliding Slotted Munition with High Aspect Ratio Lifting Surfaces

In order to improve the capability of design aerodynamic of the guided munition, other tools were developed or are being applied for these design tasks (Fig. 15). Among them: Vortex–Lattice method with an engineering correction factors obtained from CFD runs as well gliding, maneuver 3 DOF trajectory prediction and performances analysis. Also it was assembled a simplified engineering code using non-linear vortex lattice for the wing/fins analysis and cross flow theory for the body (Mugap Code\textsuperscript{9,11}). Euler and RANS codes are being applied to understand the challenging aerodynamics of this kind of weapons. Comparison with a similar configuration presented in Ref. 17, shows that the methodology in development is consistent and can be used with enough confidence at least for the concept development phase.
The results for Normal Force, Pitching Moment, L/D ratio are shown in the following Figs 16a, 16b and 16c, for the MUGAP configurations at $M=0.5$, predicted with ADAM 2, Missile Datcom and Simplified Engineering Code (MUGAP code).

Fig. 16a
Maximum L/D ratio is obtained at AoA of about 5 degrees and it can be observed that Missile Datcom overpredict the L/D_{max}. at that AoA by more than 30%. The optimum gliding velocity is around 150 m/s to maximize range having enough maneuver capability as defined by the initial set of requirements.

4. Conclusions
A novel concept for guided munitions as payload for artillery rockets has been developed. A set of engineering level aerodynamic prediction tools have been assembled and validated to deal with the aero-mechanical preliminary design phase. The code ADAM 2 was modified to cope with this type of configurations and currently is the main tool for the aerodynamic design task of the guided munition. Additional efforts are on the way using numerical methods to complete the aeromechanical design tasks. It is important to remark that standard engineering level codes for missile aerodynamics are not always suitable for configurations with body slots, fin gaps and high aspect lifting surfaces.
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References:

1. Boeing, Saab Unveil Ground Launched SDB-


