Indian J.Sci.Res. 15 (2): 33-37, 2017 ISSN: 2250-0138 (Online)

PERFORMANCE ENHANCEMENT OF AEROSPACE VEHICLE OF PULSE DETONATION ENGINE (PDE) – PHASE - II

SUBHASH CHANDER[a1] AND TEJINDER KUMAR JINDAL[b]

[ab]PEC University of Technology, Chandigarh, India

ABSTRACT

PDE is emerging aerospace propulsion system option due its simpler construction, high impulse, small form factor and light weight up to hypersonic velocities. A large numbers of researchers worldwide, are engaged in design of optimal PDE for aerospace applications due these advantages. Pulsating power delivery issue of this engine can be handled by high frequency multicycle operations, which will be able to deliver near continuous power for limited intervals at least in short duration missions. PEC has also developed a ground demonstrator cyclic PDE and conducted several trials to obtain the key performance data in terms of thrust, pressure and thermal areas etc. under varied ambient, fuel/air flow rates and ratios including detonation energy exploitations. The data is analyzed and characterized to better the performance of the engine. System engineering of a weapon system has been carried out by replacing its secondary part of rocket propulsion by PDE engine. Point mass analysis of the weapon system is carried out by developing a model of weapon system powered by PDE. A comparison is analytically and graphically drawn to examine the trends of performance improvements. Novel enhancements options have been tried to reach optimum performance. The paper deals in the point mass model development and performance computation after using these enhancement schemes in this simplified model of the aerospace vehicle, in addition to their theoretical and practical addressing strategy adapted by PEC team to make the system feasible. After cycles of iterations, performance of the weapon system is improved between 20-30% including several other enhancements of features of the weapon system. This has made PDE as suitable application as sustainer for current weapon system in consideration.

KEYWORDS: Thrust, Point Mass Model, Impulse, Performance, Detonation Engine.

The typical configuration of weapon system (WS-PEC) is as shown simplified 2 D force diagram in fig.1. The resolving the forces are depicted in fig.2. To create point mass model from this, lift and drag forces are ignored and the resultant force diagram is left with thrust and weight forces. The further analysis is based on this simplified model of weapon by incorporation of PDE engine as sustainer.

The missile rocket motor used as booster thrust profile is created through nominal look-up table in time history profile. This is interpolated at fixed intervals to get thrust values at pre-fixed intervals. Another table of variation of mass is also created through nominal mass decrease look–up table in time history, which is interpolated for pre-fixed interval values. Another look-up table is created for PDE based sustainer propulsive thrust and mass change history. The proposed configurations for PDE firing were as under:

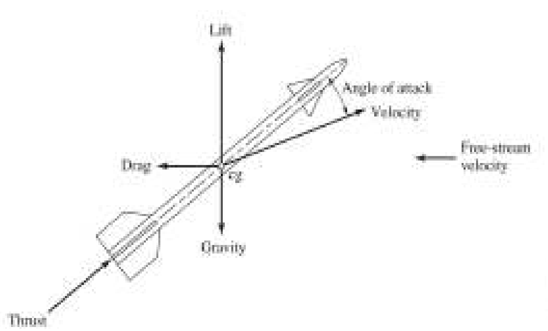

Fig.1 Simplified Force diagram of Missile

- Firing one at a time
- Firing two together
- firing four simultaneously
- firing all eight simultaneously

These operations are carried at various frequencies from 0.5 to 25 Hz. Optimum configurations are two tube firing together (which are located at 180º apart) at 16 hz and is feasible to achieve in present schema. Firing of sustainer was also tweaked. It was tried from 3.6 sec to 7.5 sec. Optimum feasible operating time of sustainer 4.0 sec.

The analytical model is developed and data generated through this model is analyzed.

Firstly, in the missile model with existing booster, a nominal thrust look-up table is obtained with respect to time from previous testing. Another nominal look-up table for mass variation is obtained with respect to time from previous testing of booster. Now this has been further enhanced using better iterative processes.

The software program for the above algorithm by embedding of various features, is created to provide detailed study into various aspects of current problem. It included iterating in no. of tubes, mass of oxidizer/fuel, firing sequence and timings etc. to create several cases. The best case obtained is with 8 tubes, 2 fired (91 times)

[1]Corresponding author

simultaneously to augment thrust at 16 hz (62.5 mS time interval gap between two firings) frequency for better range, more lateral acceleration (latax) for terminal kill steering, significant intercept speed coupled with less flight time/vibrations. It will result in less cross-coupling effects as the tubes chosen for this firing are 180° apart. The mass change profile is plotted. From this analysis, it is established that there is a significant increase in launch weight and some higher weights even at terminal phases. This weight increase is a penalty to the complete system. After cycles of iterations, performance of the weapon system is improved between 20-30% including several other enhancements of features of the weapon system. This has made PDE as suitable application as sustainer for current weapon system in consideration.

CONCEPTUAL DESIGN MODELLING

To start the work preliminary work was started, following design modeling techniques are implemented using Mathworks Matlab:

Model Used	Forces Considered
1 DOF	Axial force (Using C_{d0}), Thrust, weight
2 DOF	Normal force (Using C_N), Axial force (Using C_{d0}), Thrust, weight
3 DOF (Point mass)	3 forces (Normal force (Using C_N), Axial force (Using C_{d0} and Side force) Thrust, weight

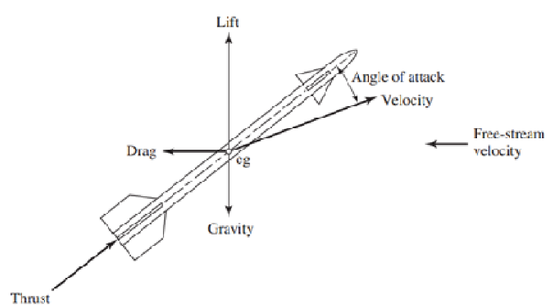

Figure 1: Simplified Force diagram of Weapon System

VECTOR FORCE DIAGRAMS AND ANALYSIS

The various forces acting on the WS-PEC are resolved in X-Z plane. The forces acting in yaw domain are also ignored temporarily as this analysis is quite preliminary in nature. However, it is observed that the effect of such forces may be negligible as compared to other important forces (< 4 % nominal). The equations are derived as below by applying vector resolving in XZ plane (assuming CG and CP coincide and no thrust misalignment):

The WS-PECforces are resolved in axial and normal forces. The derived simplifiedforces diagram is as figure 2:

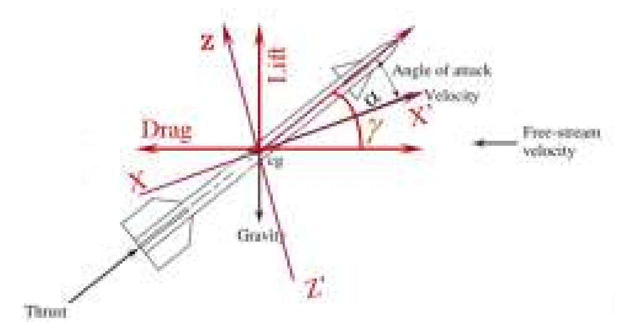

Figure 2: Resolving Forces of Weapon System

First Dynamic pressure,

Using Dynamic Pressure (Dyn) in effective area (S) in lift (L) and drag (D) equations (equation VI and VII), L and D are computed.

$$h_{km} = \frac{z}{1000}$$

$$\rho = 1.151943 - 0.1014426 \times h_{km} + 0.0027712 \times h_{km}{}^2$$

$$Dyn = \frac{1}{2} \times \rho \times v^2$$

$$v_{sound} = 350.0907 - 4.12537 \times h_{km}$$

$$Mach = \frac{v}{v_{sound}}$$

$$a = \Pi \times \frac{d^2}{4}$$

$$s = a_{total} = a \times \frac{110}{100}$$

$\because$

10% more for control surfaces, protrusions etc.

Using Dynamic Pressure (Dyn) in effective area (S) in lift (L) and drag (D) equations (equation VI and VII), L and D are computed.

Resolving in X direction,

$D \cos\gamma = L \sin\gamma + Th \cos(\gamma - \alpha) + m\, a_x$ ……….. I

Resolving in Z direction,

$m\, g + Th \sin(\gamma - \alpha) + m(-a_z) = L \cos\gamma + D \sin\gamma$ ……... II

Simplifying we get

$m\, a_x = L \sin\gamma + Th \cos(\gamma - \alpha) - D \cos\gamma$ ……... III

For equilibrium in Z direction,

m (-a$_z$) = L cos γ + D sin γ -[m g+Th sin (γ- α)] ….. IV

Using these values of L, D, α and γ (Computed as per equation VI), forward acceleration a_x, vertical acceleration a_Z and total acceleration a are computed.

The same can be rewritten in instant form as below:

$$a_x = \frac{L\times\sin\gamma + Th\times\cos(\gamma-\alpha) - D\times\cos\gamma}{m}$$

$$-a_z = \frac{L\times\cos\gamma + D\times\sin\gamma - [Th\times\sin(\gamma-\alpha) + m\times g]}{m}$$

$$a = \sqrt{a_x^2 + a_Z^2}$$

Velocities can be computed by integrating accelerations:

$$v_x = \int_{t=t-t_s}^{t=t} a_x \, dt$$

$$v_z = \int_{t=t-t_s}^{t=t} a_z \, dt$$

The same can be written in instant form as below and total velocity v is computed:

$$v_x = v_{x\_previous} + a_x \times t_s$$

$$v_z = v_{z\_previous} - a_z \times t_s$$

$$v = \sqrt{v_x^2 + v_z^2}$$

Velocities can be computed by integrating accelerations:

$$x = \int_{t=t-t_s}^{t=t} v_x \, dt$$

$$z = \int_{t=t-t_s}^{t=t} v_z \, dt$$

$$x = x_{previous} + v_x \times t_s$$

$$z = z_{previous} + v_z \times t_s$$

Flight attitude angle γ is computed vectorially as per equation.

$$\gamma = \tan^{-1}\left(\frac{-v_z}{v_x}\right)$$

Similarly, positions of WS-PEC are computed:

$$r = \sqrt{x^2 + (z_0 - z)^2}$$

$$x_{tnew} = x_t - x$$

$$z_{tnew} = z_t - z$$

These equations are modeled in Matlab and test data was generated.

RESULTS & DISCUSSION

The software program for the conventional algorithmby embedding of various features, is created to provide detailed study into various aspects of current problem. It included cross plotting of the data with conventional booster sustainer configration (red) Vs without sustainer (black) in figure 3. It clearly depicts that performance of the missile is detorated byh removal of sustainer and range of the missile got reduced by 300+ m.

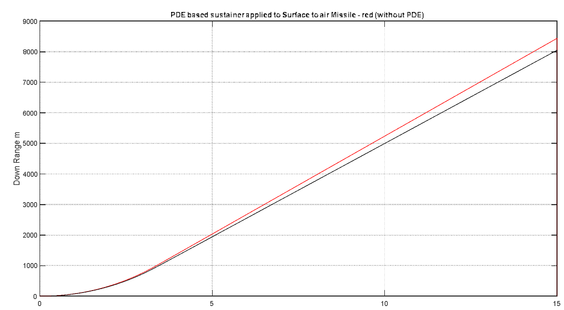

Figure 3: Conventional and modified configuration of Weapon System – plotting of down range

The software program for the above algorithmby embedding of various features, is created to provide detailed study into various aspects of current problem. It included iterating in no. of tubes, mass of oxidiser/fuel, firing sequence and timings etc. to create several cases. The best case obtained is with 8 tubes, 2 fired (91 times) simultaously to agument thrust at 16 hz (62.5 mS time interval gap between two firings) frequency for better range, more lateral acceleration (latax) for terminal kill steering, significant intercept speed coupled with less flight time/vibrations. It will result in less cross-coupling effects as the tubes chosen for this firing are 180° apart. There is a significant increase in launch weight and some higher weights even at terminal phases. This weight increase is a penelity to the complete system. We observed a quantum jump in thrust due high thrust produced by PDE system. The latex is also significantly improved and is more clearly figured out. The key features of this configration are analysed by our research team. Since lateral acceleration (latex) is high, which will help missile to have better intercept characterstics, resulting in improved maneuverability. Also, there is gradual increase in velocities, which will reduce time of flight. It will also help to improve surviveability as reaction time is also reduced.This has about 2 km+ range extension with 10-15% intercept speed enhancementas per figure 4. This clearly proves the suitability of PDE for sustainer for surface to air missile application. Further refinement and related theortical reinforcement is being carried out to get further better parameters.

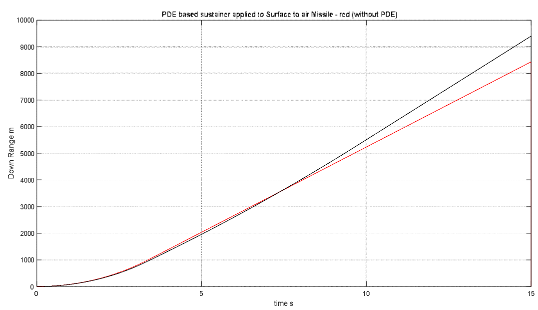

Figure 4: Conventional and PDE based modified configuration of Weapon System – plotting of down range

CONCLUSION

The effects of PDE based secondary system is carried out as basic studies theoretically and modeled in Matlab. The results obtained from simulation have shown that the system performance is improved significantly after PDE introduction. The research is underway to find the techniques to improve the performance through configurations and physical parameter variations. This have opened up new option available for propulsion, which is having better form factor and easier to maintain/operate in future.

ACKNOWLEDGEMENT

Authors are thankful to Director, PEC University of Technology and The Director, TBRL, Chandigarh for their support and guidance.

REFERENCES

Feng-Yuan Z., Toshitaka F., Takeshi M., Ei-Ichi N., Tsuyoshi H., Nobuyuki A., Satoru Y. and Azusa T., 2003. “Experimental Study of Key Issues on Pulse Detonation Engine Development”, Trans. Japan Soc. Aero. Space Sci., **45**(150):243–248, DOI: 10.2322/tjsass.45.243.

Fred S., Jeff S. and Royce B., 2001. “Detonation Initiation studies and performance results for Pulsed Detonation Engine applications”, 39th AIAA Aerospace Sciences Meeting & Exhibit, AIAA 2001-1129.

Chander S. and Jindal T.K., 2012. “Integration Challenges in Design and Development of Pulse Detonation Test Rig” International Journal of Advance Research in Electrical, Electronics and Instrumentation Engineering, **1**(4), ISSN: 2278-8875, DOI: 10.15662/ijareeie.

Frank K.L., 2016. “Progress and Challenges in the Development of Detonation Engines for Propulsion and Power Production”, Applied Mechanics and Materials, ISSN: 1662-7482, **819**:3-10.

Chander S. and Jindal T.K., 2014. “Performance Enhancement of Surface to Air Missile by Application of Pulse Detonation Engine based Secondary Propulsion System”, International Journal of Mechanical Engg. (IJME), Recent Science Publications.

Chander S. and Jindal T.K., 2013. “Design of Automated Fire Control System for C2H2/O2 Pulse Detonation Rig”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, **2**(2), ISSN: 2278-8875, DOI: 10.15662/ijareeie.

Jindal T.K., 2012. "Pulse Detonation Engine - A Next Gen Propulsion", International Journal of Modern Engineering Research (IJMER), **2**(6), ISSN: 2249-6645.

Jindal T.K., 2012. “Single Cycle Pulse Detonation Engine Testing”, International Journal of Mechanical Engineering, ISSN 2051-3232, **40**(10).

McManus K., Furlong E., Leyva I. and Sanderson S., 2001. “MEMS-Based Pulse Detonation Engine for Small scale Propulsion Applications”, AIAA paper 2001-3469.

Mahaboob Valli D. and Jindal T.K., 2013. “Thrust Measurement of Single Tube Valveless Pulse

Detonation Engine," International Journal of Scientific and Engineering Research (IJSER), **4**(3), ISSN 2229-5518.

Falempin F., Bouchaud D., Forrat B., Desbordes D. and Daniau E., 2001. "Pulsed Detonation Engine Possible Application to Low Cost Tactical Missile and to Space launcher", AIAA-2001-3815, 37th AIAA/ASME/ SAE/ASEE Joint Propulsion Conference, Salt Lake City, Utah.

Smirnov N., Nikitin V.F., Biochinto A.P., TyurniKov M.V., ShevtSova V.M. and BaskaKov V. V., 1999. "Proceedings of the 12th ONR Propulsion meeting".

Roy G.D., Frolov S.M., Borisov A.A. and Netzer D.W., 2014. "Pulse detonation propulsion: challenges, current status, and future perspective", Progress in Energy and Combustion Science 30, www.sciencedirect. com.

Chander S., Mahaboob Valli D. and Jindal T.K., 2013. "Multiple Option Levels Based Full Function PEC Aero Simulation (PAeroSim) Development for Pulse Detonation Engines & Systems", Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD 2013), Hyderabad, India.

Schauer F. and Stutrud J., 1999. "AFRL's In House Research Pulse Detonation Engine". 11th Annual Symposium on Propulsion.

Chao T.W., Winterberger E. and Shepherd J.E., 2001. "On the Design of Pulse Detonation Engine", Galcit Report FM00-7, Graduate Aeronautics Laboratories, California Institute of Technology.

Jindal T.K. and Chauhan Y.S., 2012. "Development of Pulse Detonation Rig", A Report on sponsored research by TBRL.

Chander S., Singh S., Ray S.K., et. al., 2008. "System Engineering for Antiship Missile – a report", RCI, Hyderabad.

Lam M., Tillie D., Leaver T. and McFadden B., 2004. "Pulse Detonation Engine Technology: An Overview", Submitted to: Michael Schoen, Applied Science 201, The University of British Columbia.

Travis J. and Kring J., 2009. "Labview for Everyone", Pearson Education.

Thomson W.T. and Dahleh M.D., 1998. "Theory of Vibration with Applications", Fifth Edition, Prentice Hall, Inc.

Fleeman E., 2006. "Tactical Missile Design", AIAA Education, ISBN-10: 1563477823.