

## SIMULATION OF RAM ACCELERATOR WITH PETN LAYER

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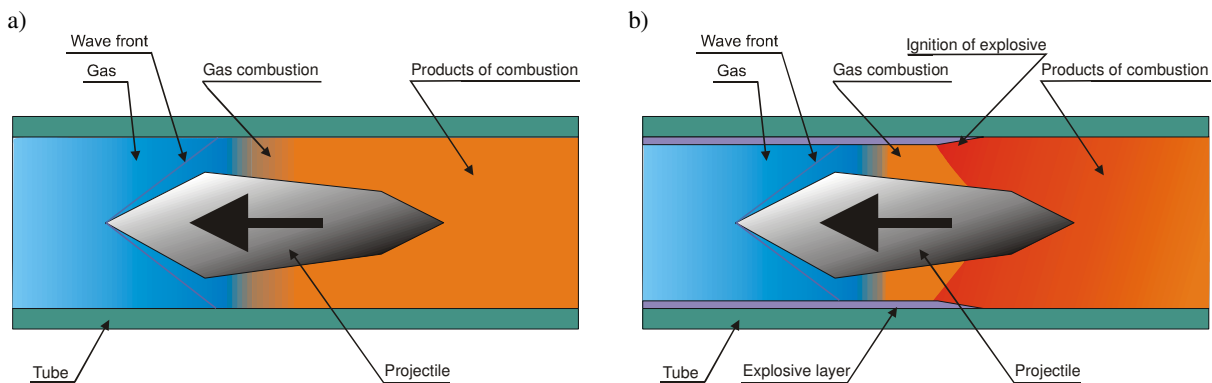
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**Summary** The paper presents a new idea of ram accelerators with high explosive layer. The layer is an additional source of chemical energy which enhances thrust generated by the device. In the paper there is described model of flow and two-phase combustion in ram accelerator. Results of numerical simulation show that it is possible to increase the thrust about several percent.

### INTRODUCTION

Ram accelerators are a new type of hypersonic propulsion known since 1980's [4]. Basic idea of the ram accelerator base on utilizing chemical energy released during combustion of gaseous mixture caused by high velocity projectile. In the conventional ram accelerator high velocity projectile generates shock waves which ignite combustible gaseous mixture. Combustion of gas leads to increase of pressure in rare part of projectile and generates thrust (Fig. 1 a). Proposed modification depends on addition of high explosive layer. Combustion of gas causes ignition of the layer and releases of additional heat. It should give a rise of thrust (Fig. 1 b).



**Fig. 1. a) Conventional ram accelerator, b) ram accelerator with high explosive layer.**

Possibilities of enhancing of performances is studied in this work. A numerical simulation of the device is used in order to get information about increase of thrust.

### THEORETICAL MODEL

A two-dimensional model of the ram accelerator with PETN layer consist of two parts:

- flow and chemical reaction model of gas,
- heat conduction and chemical reaction model of high explosive.

First model is based on Euler equation of reactive gas with global reaction chemistry. Such model was successfully used in simulation of gaseous detonation and conventional ram accelerators.

Model of combustion of high explosive is based on equation of heat conduction with source term. Decomposition of high explosive is described by Arrhenius' law. Parameters of kinetics of high explosive decomposition were taken from experimental data for PETN [1],[5]. Interconnection between gas flow model and model of PETN layer was realised by boundary condition. There is used Sichel's theory of heat exchange behind detonation front [2],[3]. This theory was chosen because physics of combustion in ram accelerators is very similar to detonation. The model was used in simulation of ignition of PETN layer by gaseous detonation and gave good qualitative agreement with experiments.

### RESULTS

Described model was used in simulation of ram accelerator working with  $H_2-O_2$  mixtures. The mixture composition was 40%  $H_2$  and 60%  $O_2$ . Calculations were carried out in superdetonative mode for velocity ranging from 2300 to 4000 m/s. They proved that it is possible enhance performance of the device. Layer ignites enough quickly. Combustion of the PETN layer causes increase of thrust from 11% for  $V=2300$  m/s to  $\sim 0$  for  $V=3250$  m/s for lower initial pressure and from 6% for  $V=2400$  m/s to 1.5% for  $V=4000$  m/s for higher pressure (Fig. 2). Comparison of pressure field around projectile shows that additional thrust is generated mostly in rare part of projectile (Fig. 3). Next observation is that only very thin part of layer was burnt in neighbourhood of projectile.

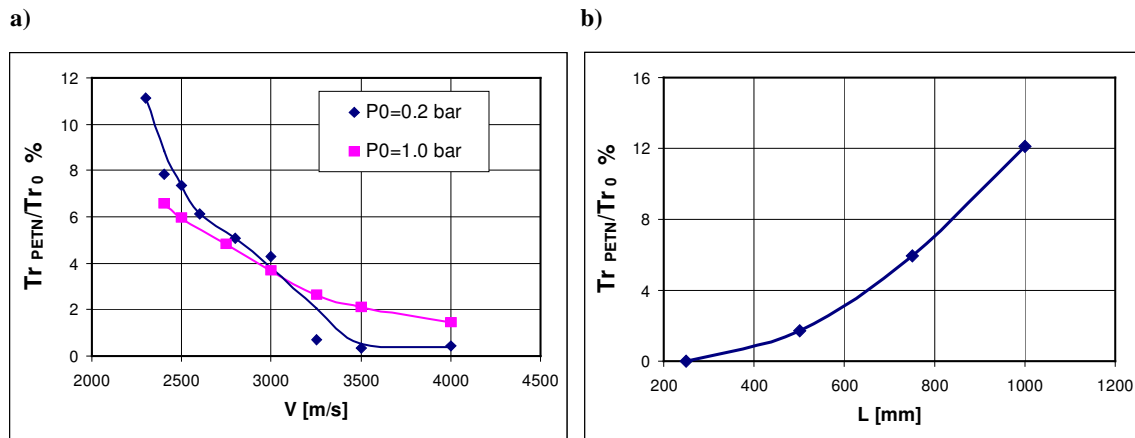


Fig. 2. a) Increase of thrust caused by combustion of the layer as a function of velocity for various initial pressures (mixture: 40% H<sub>2</sub>, h=1mm). b) Relation between thrust enhancement and length of projectile (mixture: 40% H<sub>2</sub>, h=1 mm, V=2400m/s).

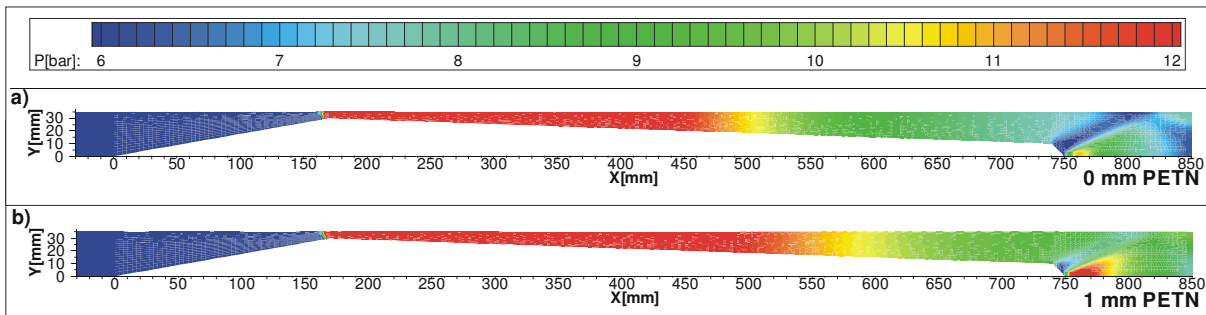


Fig. 3. Pressure field in: a) the conventional ram accelerator, b) the ram accelerator with the layer of high explosive,  $V = 2400$  m/s, gaseous mixture: 40% H<sub>2</sub> + 60% O<sub>2</sub>,  $p_0 = 1$  bar,  $h_{layer} = 1$  mm.

## CONCLUSIONS

Simulation of modified ram accelerator shows that combustion of PETN layer is a good way to improve its performance. Applied numerical model is sufficient and allows analysis of influence of different parameters of ram accelerators on thrust e.g. geometry of projectile, kind of high explosive. Carried out calculations allow formulating following conclusions:

1. The combustion of the PETN layer causes increase of thrust of several percent.
2. Only very thin part of the layer contributes to the thrust increase.
3. The influence of the PETN decomposition decreases at higher velocities.
4. There is a strong dependence between the projectile length and increase of the thrust.
5. The thrust increase does not depend on the layer thickness if it is thicker than 0.2 mm.
6. There exists an optimal composition of gaseous mixture which ensures the best utilisation of the layer.

Results of analysis also point out the ways of further improvements. Especially important may be increasing of rate of PETN burning e.g. by developing of layer surface.

## References

- [1] Kobiera A., Wolanski P., Ignition of liquid and dust fuel layers by gaseous detonation. *Shock Waves*, Vol. 12, No 5, 2002
- [2] Sichel M., David T.S.: Transfer behind Detonations in H<sub>2</sub>-O<sub>2</sub> Mixtures. *AIAA Journal* Vol 4, No. 6, 1966
- [3] Sichel M., Rao C.S., Nicholls J.A.: A simple theory of film detonation: *Thirteenth Symposium on Combustion*. The Combustion Institute, Pittsburgh, Pennsylvania pp 1141-1149, 1971
- [4] Takayama K., Sasoh A. (Eds.): Ram Accelerators, *Proceedings of Third International Workshop on Ram Accelerators Held in Sendai, Japan 1997*, Springer-Verlag, Berlin Heidelberg New York, 1998
- [5] Wolanski P., Kobiera A.: Experimental and numerical research on interaction between gaseous detonation and solid explosive. *19th International Colloquium on the Dynamics of Explosions and Reactive Systems*, Hakone, 2003