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NUMERICAL SIMULATION OF INTERMEDIATE BALLISTICS FOR GUN AND ROCKET SYSTEMS

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This paper describes some solutions for computer-simulated gasdynamic processes peculiar to rocket and artillery systems transient functioning modes. The solutions presented herein were obtained with the help of a multi-purpose CFD package *GasDynamicsTool*. The adequacy of the computational procedure describing intermediate ballistics processes is supported by way of comparing the calculated data with experimental ones. The solution of initial system of equations is based on an explicit version of the finite volume technique using a uniform Cartesian grids. The package has variety of submodels including two-phase processes description with chemical reactions in both phases The computational procedure elaborated is shown to be effectively implementable on usual PC's.

INTRODUCTION

Weapon systems performance during transient stages of operation presents a complex and multifaceted phenomenon. This work is devoted to the description of numerical modeling routines as applied to the solution of gasdynamics problems pertaining to the operation of rocket and artillery systems. Of course, there is no way of fully addressing the whole diverse range of the processes involved; it will therefore be appropriate to first tackle the issues of paramount importance. Above all, these are the transient processes of intermediate ballistics, i.e. propellant gases afteraction on the projectile; processes in muzzle heads like muzzle brakes and mufflers; mine or rail rocket launches; multiple warheads separation; rocket engine off-design modes of operation, etc. The main difficulties in simulating such processes proceed from the complexity of their physical and chemical nature as well as a non-trivial formulation of boundary conditions. As far as geometry is concerned, such problems involve 2- or 3-dimensional environments in the presence of complex geometry bodies whose surfaces are often not to be reduced to a combination of simpler standard shapes like sphere, parallelepiped, cone, axisymmetric figures, etc. The result is that such a flowfield has a lot of mutually interacting discontinuities, which, in view of the unsteady character of the problems considered, imposes tough requirements both to the quality of the computational schemes and the computational resources used in the simulation. To demonstrate the high quality and multi-purpose character of the algorithms evolved, four most representative types of gasdynamic processes are considered in this paper: muzzle brake operation; propellant gases ulterior action on projectiles; muzzle muffler operation; rocket systems launch gasdynamics.

It has to be noted that some of the figures in this publication were initially done in colour grades and then reduced to a black-and-white version. It is therefore not always that the regions with a similar intensity of gray in parameter distribution correspond to equivalent magnitudes of these parameters.

TESTING

A most important aspect of the CFD program's operating is adequacy in describing physical processes. The essence of the group of tests conducted consists in comparing the computed results obtained with experimental data. Compared are the geometric characteristics of the flowfield, the shape and position of the shock waves, contact discontinuities, etc.

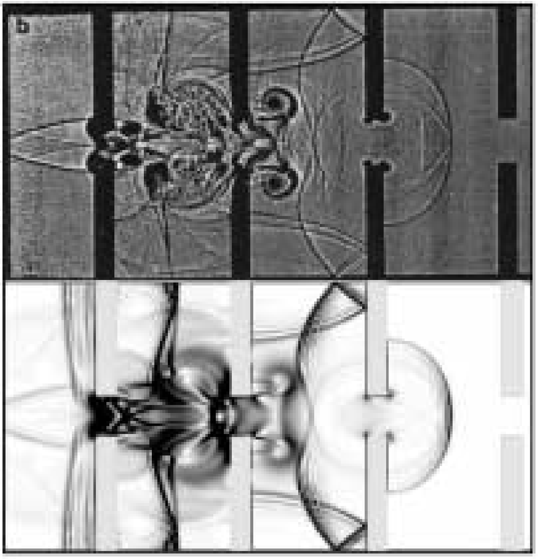

Figure 1. First density derivative module distribution (below) and a shadowgraph of the shock wave propagating thru a buffle.

The importance of this kind of tests lies in the fact that the qualitative characteristics of the flows are indispensably related to the geometric ones. Should the value of any parameter in a certain point of the flow be determined erroneously, it will invariably affect the adjacent regions and, ultimately, will bring about a distorted flowfield picture, an erroneous shock-wave shape, an inadequate spatial position of discontinuities. Fig. 1 shows an example of such a comparison. This comparison shows quite a satisfactory agreement of the numerical and experimental [1] data. Despite the multiple reflections and the presence of high-gradient zones, vortexes and other non-linear formations in the flowfield the program features good agreement in the discontinuities position which testifies to the correct numerical description of the spatial distribution of all the gasdynamic parameters and laws of their evolution. Shadowgraphs do not represent the full information on density distribution as such but rather on discontinuities position in this distribution. It is therefore sensible to compare experimental data with the highest density derivatives.

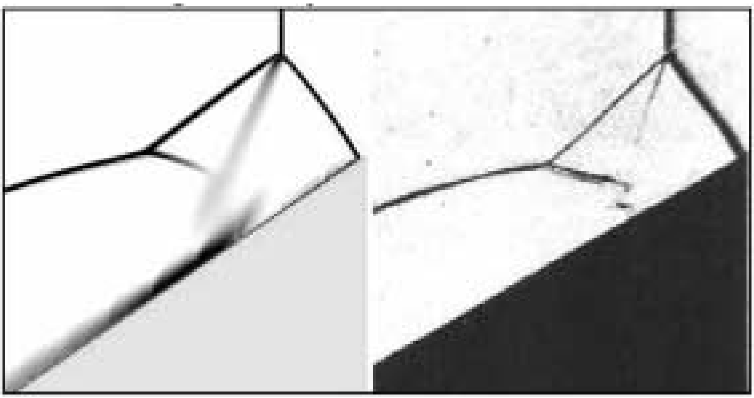

Figure 2. Comparison of first density derivative distribution (left) and experimental shadowgraph.

Fig. 2 presents the module distribution for the first density derivative and shadowgraph data [2] for an irregular reflection of the shock-wave from a wedge with the formation of two triple points. This rather infrequent phenomenon manifests itself in a very narrow interval of wedge angles at a high-intensity incident wave. It is seen that the calculated and experimental data agree well. This test confirms the feasibility of numerically simulating complex non-linear gasdynamic processes as well as of adequately describing gasdynamic phenomena with the help of the model evolved, which features a capability to simulate processes physically, mathematically and by way of the finite differences technique. In view of the broad applicability of the package discussed to problems related to unsteady high-gradient jet flows, a series of tests was accomplished for this specific range of flows. Fig. 3 compares shadowgraph data for the initial phase of the supersonic jet discharge with the results of a numerical experiment (the first density derivative). In the figure a reverse shockwave is quite evident – a phenomenon that is rather troublesome to simulate.

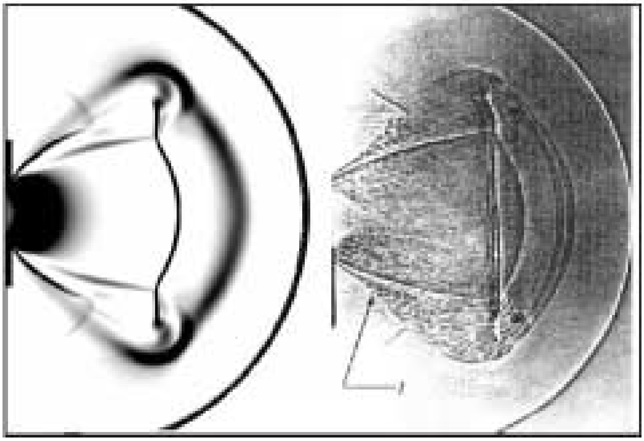

Figure 3. The initial stage of a supersonic jet discharge. On the left is the distribution of the first density derivative.

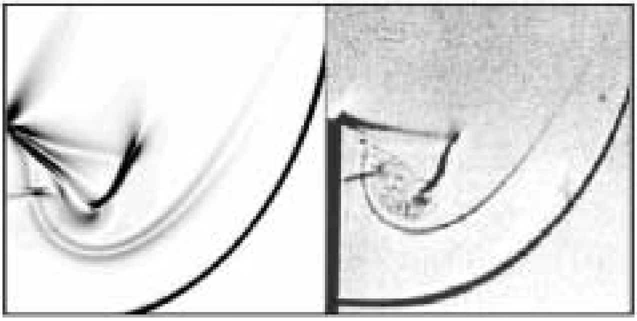

Figure 4. Shockwave diffraction. On the left is the distribution of the second derivative of density. On the right shadowgraph data (Van-Dyke, 1986) are presented.

The general picture of the flow is represented by the computational data obtained quite satisfactorily. Fig. 4 shows a comparison of the second density derivative with shadowgraph data [2] with a strong (M=7) shockwave diffraction at a right angle. The numerically obtained flow features the main attributes of the phenomenon – a breakdown wave, a vortex on its lower edge, the first and the last characteristics of the rarefaction fan, the contact surface and the slipline.

It is obvious that not only does the computational package represent the spatial poison and shape of these formations, but also their intensity. It is to be noted that in the above mentioned examples the flowfields simultaneously contained both subsonic and supersonic regions as well as contact and tangential discontinuities and vortexes. The differential scheme, the physical and mathematical model and the resultant computer code do adequately describe the simulated phenomena. It will also be pointed out that a high computational precision in solving such complex problems can only be achieved due to a high-quality algorithm and an effective code realization. When testing the *GasDynamicsTool*

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package [3] a large number of numerical experiments were held for various flow modes and most diverse initial and boundary conditions. In most cases (especially in those discussed here) good qualitative and quantitative agreement of numerical and experimental data was obtained.

MUZZLE BREAK

As a rule, a MB consists of one or several chambers in which the powder combustion products expand and are deflected through dedicated orifices creating a pulling pulse, which results in the reduction of the recoil pulse. It must be noted that all the problems related to MB processes modeling are essentially three-dimensional. This circumstance imposes tough requirements on applied program packages in the way of the computational speed and memory size. The simplest 3D computations accounting more or less for real MB geometry involve hundreds of thousands or millions of 3D cells. The *GasDynamics-Tool* package is capable of handling such grid sizes.

Figure 5. Pressure distribution in the intermediate ballistics period for a gun with muzzle break.

Fig. 5 presents the results of solving a gasdynamic parameters problem both inside and outside the MB. Body sections are shown in black. The figure depicts pressure distribution for 12 consecutive time points, the interval of data output for the first six frames being twice as short as for the other ones. At the initial stage of the projectile's leaving the barrel (1–3) the shockwaves are highly intense and it overtakes the projectile. This effect is seen on frames (4–9) where a powerful reflected secondary wave is formed while the projectile is passing a baffle. Fragments (10–12) feature the formation of the Prandtle-Mayer flow at the discharge edge of the muzzle brake and the initial phase of the projectile's free ballistic flight.

ULTERIOR ACTION ON PROJECTILE

The computation procedure is analogous to the previous one except it was solved for the projectile's quiescent reference frame. It can be seen that many of the above mentioned qualitative characteristics are valid for this flow type as well, though it is quite obvious at the same time that the peculiarities of various projectile designs do influence the loads distribution pattern and their temporal dependence.

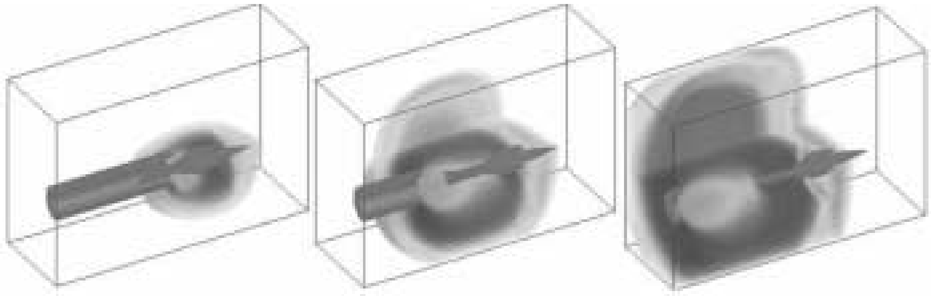

Figure 6. Pressure distribution in the initial stage of the afteraction period.

It is well seen that in the initial phase the shockwave and the contact discontinuity overtake the projectile in which period the latter experiences maximum gasdynamic loads. Next the gas flow and the projectile travel at a low relative speed and the projectile is practically free of loads. Finally, the projectile gradually leaves the perturbed flow and enters the stage of a free ballistic flight. Fig. 6 presents pressure distribution in a semi-transparent colour scale. The nearest plane is that of symmetry. For a better view a cut-out was made in the plane perpendicular to the symmetry plane along the main axis and in the plane parallel to the far boundary at a distance of 10 cells from it. The size of the computational domain was 100 x 200 x 300.

MUZZLE MUFFLER AND ROCKET STAGES SEPARATION

It is a device designed to reduce the muzzle blast intensity. As a rule it presents a series of obstacles, baffles, etc.

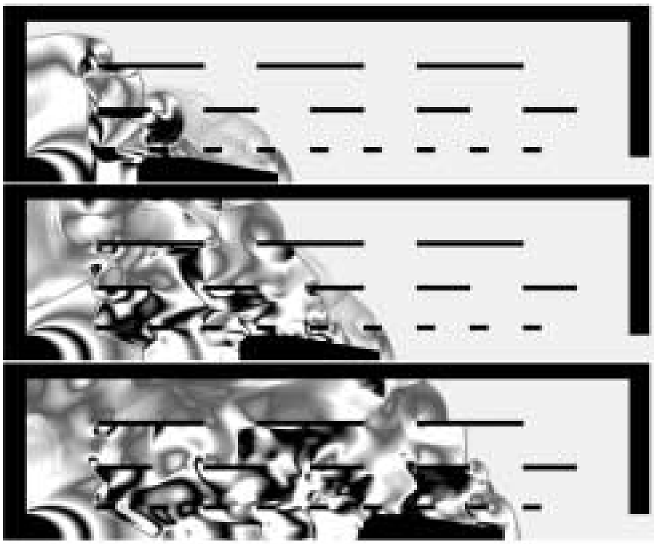

Figure 7. Muzzle muffler pressure distribution at bullet exit.

Fig. 7 presents the process of a bullet's travel through a muzzle muffler. The primary shockwave resulting from the combustion products expanding gradually overtakes the bullet and when the latter reaches the muzzle plane catches up with its front portion.

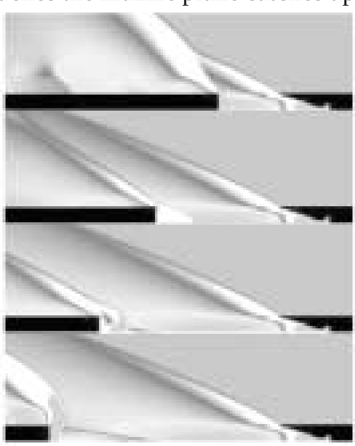

Figure 8. Stages separation in axisymmetric variant. Pressure distribution.

For a certain design geometry this effect may bring about a situation when the shockwave will converge on the symmetry axis in front of the bullet thus acoustically intensifying the discharged wave. This problem can be solved, for instance, by easing the flow propagation in the direction away from the axis and/or by changing the size of the tubes structural elements.

When jet engine systems are launched or rocket stages are separated, certain phenomena are observed resulting from jet/obstacle interaction. Several examples of the GDT code application for solving this kind of problems are discussed in the author's thesis. In the axisymmetric scenario a rocket launch at exit is modeled. Fig. 8 shows pressure fields at consecutive time points. The problem is solved for a steady state rocket. At the initial stage of the flow propagation inside the launcher there is observed the formation of a periodic structure as well as the formation of lambda shockwaves which are characteristic of this kind of flows. The solution of problems like this is useful for estimating force and temperature loads on rocket and launcher element.

CONCLUSION

All presented calculations made with use single processor PC. On a Pentium III 550 computer 1,000 iterations in the computational domain of 10,000 cells take 22 seconds. The computation of 1,000 iterations in 1000,000 cells domain takes 214 seconds which shows a linear dependence between the size of the computational domain and the computation time. When run on a 512 Mb RAM computer the package is capable (Eulerian solver was used for multicomponent gas mixtures) of computing 15,000,000 2D or 12,000,000 3D sells without swapping on additional memory resources (hard disks or peripheral devices). Such efficiency capabilities of the *GasDynamicsTool* package rank it among the best in the range of applied packages designed for numerically simulating gasdynamic processes. It makes possible to perform high-scale calculations on usual PC, use them in CAD/CAE systems for real geometries and essentially decrease funds for development, design and testing of new weapons.

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