International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-7,July 2016
ISSN: 2395-3470
www.ijseas.com

Numerical approach to study the stability of Inertial Confinement Fusion Process in spherical target

Rita Chaudhuri
Department of Mathematics, New AliporeClloge, Kolkata, India

Abstract: We discuss a numerical approach to study the stability of Inertial Confinement Fusion (ICF) process in spherical target considering the Plesset's (JAP-1954) analytical work. Stability is the key point to achieve success the controlled fusion process in the laboratory. Physical justification has been made here for the numerical work to control the ICF process. Experimental results have been discussed with our numerical work.

Keywords: Fluid Instabilities, ICF, Viscosity, Runge-Kutta technique

Introduction:

Population growth and life style of global civilization will create a situation of scarcity of electric energyby 2050 according to International Atomic Energy Agency (IAEA) report. Nowadays we are producing the electric energy by fossils-fuel, hydro, solar cell and fission process. However, fusion is one process to generate the safe energy in long term basis. There are two types of fusion process to get energy.First one is ITER-International Thermonuclear Experimental Research whichwill produce energy around 2020 by Magnetic Confinement Fusion process in Cadarche, France. However, second one is Inertial Confinement Fusion (ICF). In this paper, we present a simple numerical approach to get the controlled fusion in ICF this process. In ICF target, deuterium-tritium (DT)fuels are kept in a micro bubble at cryogenic temperature and this bubble is hold bya target of composite material. There are mainly four steps to complete this ICF process. Process are divided in laser radiation, the implosion-compression, ignite the fusion and the DT fuel burn. In the second stage (implosion-compressionsituation)some interfacial fluid instabilities like Rayleigh-Taylor (RT), Richtmyer-Meshkov(RM),Kelvin-Helmholtz (KH) instabilities occur.RT[1] instability can occur due to the action of gravity at the two fluid interfaceand RM [2] instability can occur due to the impingement of shock from heavier to lighter fluid. Again, non uniform implosion causes the shearing velocityat the interface that causes KH[3] instability. These instability can act separately or in combined [4] form.These instabilities are open threaten to scientist and researchers. It should be mitigated to success this ICF process. However, this kind of instabilities can occur from astrophysical situation like supernova explosion to laboratory physics. In ICF, process, the DT fuel is considered as lighter one having density ρ_1. After the laser radiation the target holder will be a plasma of target material of $\rho_2(>\rho_1$)than DT fuel (fig.1). So the ρ_1 fluid is surrounded by ρ_2 fluid after the laser irradiation. We will treat the problem using fluid dynamics model. However, after shock passes there is no source or sink field of in the fluid hence the fluid motion will be irrorational. Here, both the fluids are considered as ideal i.e., incompressible, immiscible and nonviscous. It is also assumed that the perturbed radius of spherical interface will be of small amplitude because after it the vorticity comes into the system.

Basic Equations& Geometry of the problem

The geometry of the physical problem has been shown in fig.1. The outer solid blue line of radius R_2 is the ceiling of the heavier fluid where as the blue dotted line represents the interface (radius of R) of two fluids and the lighter fluid is bounded by lower solid blue line of radius R_1. After laser radiation, if the perturbation surface is strictly spherical one then the interface (dotted blue line) comes closer to the lower boundary. However, due to shock passes the interface will be nonuniform like red line.

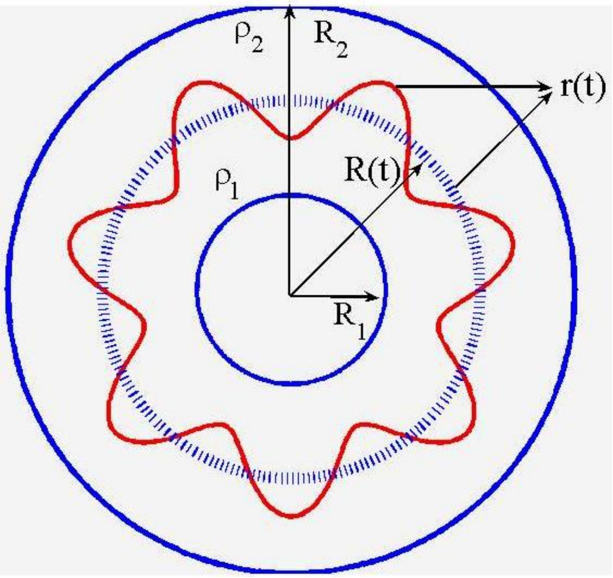

fig.1

So the interface equation will be

$$r = \mathrm{R} + aY_n \tag{1}$$

where, R,a and Y_n are the radius, angular displacement of the interface and Legendre polynomial of degree n. Since, the fluid motion is irrotational, and then there must be velocity potential for two fluids.

$$\Phi_1 = \left[\frac{R^2 \dot{R}}{r}\right] + b_1 r^n Y_n \ , \qquad r<\mathrm{R} \tag{2}$$

$$\Phi_2 = \left[\frac{R^2 \dot{R}}{r}\right] + \frac{b_2 Y_n}{r^{(n+1)}}, \qquad r>R \tag{3}$$

Where, b_1 and b_2 are two constants to be determined by boundary conditions that fluid velocities are continuous at the interface.

After some tedious but straight forward calculation, it can be easily arrived at the Plesset's[5] equation as follows:

$$R\frac{d^2R}{dt^2} + \left(\frac{3}{2}\right)\dot{R}^2 = \left(\frac{P_1 - P_2}{\rho_2 - \rho_1}\right) \tag{4}$$

$$\frac{d^2a}{d^2t} + 3\left(\frac{\dot{R}}{R}\right)\dot{a} - Aa = 0 \tag{5}$$

Where, $A = \frac{[n(n-1)\rho_2 - (n+1)(n+2)\rho_1]\dot{u}}{R[n\rho_2 + (n+1)\rho_1]}$

and P_1,P_2 are the pressure of two fluids respectively.However, Plesset did not attempt the numerical job. In this paper, main focus is on that work and physical justification of the numerical work. To do the numerical, it isconsidered that $\dot{R} = u$ and $\dot{a} = v$ and hence from eqs. (4) and (5), the following two equation can be derived easily.

$$\frac{du}{dt} = \frac{(P_1 - P_2)}{R(\rho_2 - \rho_1)} - \frac{3}{2}\frac{u^2}{R} \tag{6}$$

$$\frac{dv}{dt} = Aa - 3\frac{u}{R}v \tag{7}$$

So the following two eqs.andeqs. 5,6 will describe the motion and the velocity of the perturbed interfacealong the radial and as well as angular direction also.

$$\frac{dR}{dt} = u \tag{8}$$

$$\frac{da}{dt} = v \tag{9}$$

To solve these nonlinear eqs5,6,7,8, the Runge-Kutt-Fehlberg (5th order Runge-Kutta) technique has been followed using Matlab software package. The initial condition is one of the vital points to start this numerical job.

Results & Discussions:

The numerical results have been plotted using Matlab. The variation of perturbed radius and angular displacement and their velocity with respect to time has been plotted here. The first curve of fig.2 shows that the perturbed interfacial radius will decrease during implosion situation as the heavier fluid impinge inside the lighter fluid hence the pressure of DT fuel increases and upto a certain limit the pressure increases, then it try to blow up hence the explosion situation occur. So the perturbed radius will increase due to the reflection of pressure by the lighter fluid. However the angular displacement first increases as the radius decrease since the total mass conserved inside the spherical target and when radius will increase the angular displacement as well as the angular velocity will fall and goes to zero. In this time the radial velocity will be saturated and moving with asymptotic velocity.

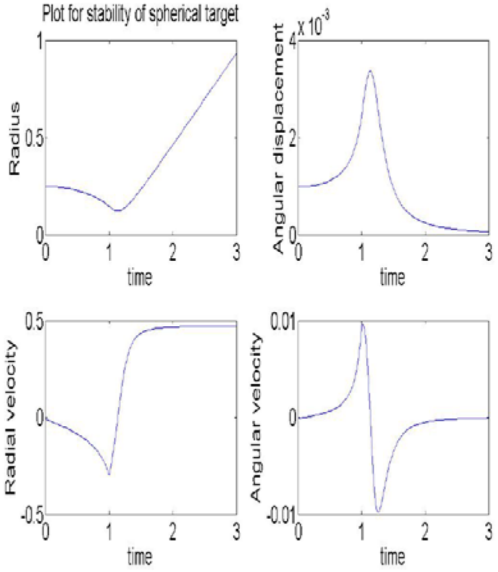

fig.2

Summary:

During implosion the heavier fluid compresses the lighter fluid and achieves the maximum compression. If Lawson’s criteria satisfy then fusion takes place. However, heavier fluid is kickedbackby lighter fluid due to reflection of excess pressure.

References:

1.Lord Rayleigh, *Scientific Papers II* (Cambridge University Press), p. 200
2. Richtmyer, Comm. Pure Appl. Math **13**, 297 (1960).
3. Nayfeeh**,** J. Fluid Mech., 55,311 (1972)
4. L.K.Mandal et al Nucl.Instru.and Methods in Physics Research A 653 103–108 (2011)
5 Plesset, Journal of Applied Phys. 25,96, (1999)