2-phase Interfacial, Droplet, Bubble Turbulence and Combustion in the Normal and Microgravity Conditions
Son Eduard

Moscow Institute of Physics and Technology, School of Airphysics and Space Technologies, Physical Mechanics Department, Laboratory of Hypersonic and Plasma Technologies, 9 Institutsky Lane Dolgoprudny, Moscow Region, Russia, 141700
E-mail son.eduard@gmail.com

“Turbulence Theory in spite of very complicated mathematics has very limited Physical Concepts”
V.M.Ievlev

Introduction
Turbulence is very common phenomena and in spite of more than 100 years research still has many conundrums. Physical approach and understanding phenomena usually based on simple examples and step by step increase the complexity of models until we reach real phenomena. From this point of view the simplest model is incompressible fluid. Studying turbulence better start from the 1D fluid flows, but due to discontinuity equation (△u_i)/△x = 0 it follows u_i = 0 for homogeneous flow. We consider developing turbulence in 2D models, of Homogeneous Isotropic then 3D taking into account consequently Gravity, Vibrations, RTI - Kapita Pendulum and Multiphase Turbulence in Droplets, Bubbles and Interface Turbulence, Reconnections, Coherent Structures, Intermittance are considered in Multiphase Turbulence.

Nature of Hydrodynamics Turbulence

Next simple model is 2D turbulence where the consideration starts from the homogeneous isotropic turbulence and cascade formation from energy to inertial and viscous intervals are considered. It is found that energy flux in spectral space is forming due to nonlinear terms with essential Obukhov time scales and viscous dissipation plays the role of BC for energy spectrum. This result gives the approach to establish specific rotational energy cascade and is generalized to 3D turbulence for different types of dissipation. As an example we considered the shir

General Approach to Multiphase Flows Turbulence

Generalized transport equation with the boundary conditions inserted into the equations

\[
\frac{\partial}{\partial t} \phi_a \rho e + \nabla \cdot \phi_a \rho \mathbf{u} = -\nabla \cdot \phi_a \mathbf{i} + \phi_a Q_{\delta \omega} + \phi_a Q_{\delta \phi} \delta_S + \\
+ \rho_a \xi (\mathbf{u} - D) \cdot \nabla \phi_a + \mathbf{i} \cdot \nabla \phi_a.
\]

Fig.2. 2D Turbulence Spectra Enstrophy and KE

For the momentum equation \( \xi = \mathbf{u} \), \( \mathbf{i}_x = \mathbf{T} \),

\[
Q_{\delta \omega} = \rho g, \; Q_{\delta \phi} = \alpha \kappa \eta \text{ we find out}
\]

\[
\frac{\partial}{\partial t} \phi_a \rho \mathbf{u} + \nabla \cdot \phi_a \rho \mathbf{u} \mathbf{u} = \nabla \cdot \phi_a T + \phi_a \rho g + \phi_a \alpha \kappa \eta \delta_S + \\
+ \rho_a \mathbf{u} (\mathbf{u} - D) \cdot \nabla \phi_a - \mathbf{T} \cdot \nabla \phi_a.
\]

For the energy equation \( \xi = e \), \( \mathbf{i}_x = f_x \), \( Q_{\delta \phi} = \alpha \kappa D \) :

\[
\frac{\partial}{\partial t} \phi_a \rho e + \nabla \cdot \phi_a \rho e \mathbf{u} = -\nabla \cdot \phi_a \mathbf{i} + \phi_a \alpha \kappa D \delta_S + \\
+ \rho_a e (\mathbf{u} - D) \cdot \nabla \phi_a + \mathbf{j}_{ae} \cdot \nabla \phi_a.
\]

Multiphase Turbulence Moments Equations

In this subsection we will average multi-phase equations (42, 43) with the next averaged variables:

\[
\Phi_a = < \phi_a >, \; \Psi_a = < \phi_a \psi > \; \text{for any} \; \psi, \; \mathbf{u}_a = \phi_a \mathbf{v}_a, \; \mathbf{u}_a = U_a + \mathbf{u}_a',
\]

\[
U_a = < \mathbf{u}_a > = < \phi_a \mathbf{v}_a >, \; \mathbf{u}_a' = (\phi_a \mathbf{v}_a)' \;
\]

Below to simplify notations for Stokes stress tensor in some formulas, where evident, we put \( \sigma^\delta \equiv \sigma \).

Averaging local phase mass (42) and momentum (43) equations we find out MPRANS (Multi-Phase Reynolds Averaged Navier-Stokes) equations for multi-phase flow.
\[
\frac{\partial \rho_a}{\partial t} + \nabla \cdot \rho_a U_a = 0, \quad \text{(51)}
\]

\[
\rho \left( \frac{\partial U_a}{\partial t} + \nabla \cdot U_a U_a \right) = -\nabla \rho_a \cdot p_a + \nabla \cdot (\sigma_a + \sigma_p^f) + \Phi_a p_g + m_a.
\]

Additional terms representing corrections to interfacial pressure and surface tension:

\[
\Delta F_a^{pi} = \left( p - p_a' \right) \nabla \varphi_a > 0,
\]

\[
\Delta F_a^{ai} = \frac{\alpha}{2} \left( \kappa - \kappa_a' \right) \nabla \varphi_a > 0.
\]

Reynolds stresses in the used variables are

\[
\sigma_a^f = -\rho < u' u' >.
\]

Rewrite the equation (52) in the form

\[
\rho \left( \frac{\partial U_a}{\partial t} + \nabla \cdot U_a U_a \right) = -\nabla p_a + \nabla \cdot (\sigma_a^f + \sigma_p^f) + \Phi_a p_g + m_a.
\]

where \( m_a \) is the phase momentum transfer force defined by

\[
m_a = \left( p_a' + \frac{\alpha}{2} \kappa_a' \right) \nabla \Phi_a - \sigma_a^f \nabla \Phi_a + \Delta F_a^{ai} + \Delta F_a^{pi}.
\]

Finally, the full set of equations for multi-phase flow consist of mass and momentum equations for each phase (51), (58) and the equation of full mass conservation which follows from the averaging the equation (36)

\[
\sum_a \Phi_a = 1.
\]

This set of equations slightly different from Drew [26] equations and more convenient for computer simulation.

Closures

This filtering process generates fewer equations than unknowns, and so further constitutive relations must be provided by \( m_a \) - forces due to a) viscous drag, b) wake and boundary layer formation, c) virtual mass and lift effects. \( S_a \) - subfilter length intraphasic stress terms should include a) dissipation of energy from resolved to unresolved scales (eddy viscosity model), b) back-scatter from unresolved to resolved scales c) Droplet induced turbulence, d) effect of stratification and buoyancy, e) expressions the \( p_a', \kappa_a' \) and interfacial pressure and curvature \( \Phi_a', \kappa_a' \).

As the first approximation we can use

\[
p_a = \Phi_a p,
\]

\[
m_a = 0 \quad \{ p_a' = 0, \kappa_a' = 0, \sigma_a = 0, \Delta F_a^{ai} = 0, \Delta F_a^{pi} = 0 \}.
\]

Below we will discuss the closure for interfacial terms in more details.

We use eddy viscosity ideas to model the stress tensor \( \sigma_a \)

\[
\sigma_a = 2 \rho_a (\Phi_a \nu_a^m + \nu_a^f) S_a,
\]

where

\[
S_a = \frac{1}{2} \left[ (\nabla u_a + (\nabla u_a)^T) \right]
\]

Here \( \nu_a^m \) and \( \nu_a^f \) are the molecular and turbulent viscosities of phase \( a \). Smagorinsky type models, see 66] for example, relate \( \nu_a' \) to the second invariant of \( S_a \), the spatial filter scale \( L \) and grid-size \( \Delta x \). With \( L = \Delta x \)

\[
\nu_a' = C_s \Delta x^2 \left[ S_a : S_a \right]^{1/2}
\]

and \( C_s \) is the Smagorinsky constant \( C_s \approx 0.1-0.2 \).

Multiphase scales

Inhomogeneous Interfacial Turbulence

References

