Conclusions and further scope of research

Conclusions

The phenomena for exploration in this thesis have been atmospheric vortices such as dust devils, tornadoes and hurricanes. The **chapters 3** and **4** have been devoted to mathematical modelling exploring characteristics of dynamics of whirlwinds. The models have been applied to investigate dynamics and genesis of dust devils. In chapter 3 which deals with mature whirlwind, it is concluded that a low pressure region within an atmospheric vortex is essentially required to keep them whirling, without which centripetal force required for rotating motion cannot be created. This has been termed as a fundamental characteristics. The model comprises axial and azimuthal velocities and no radial velocity. The axial velocity contains a parabolic logarithmic term which has been invariably absent in all previous models, which reduces the magnitude and signifies the presence of a low pressure region within the whirlwind.

Chapters 4 which introduces radial velocity in order to investigate the genesis of rotation lead us to conclude that the inflow parameter which is present in the radial velocity and its dependence on viscosity and density of the wind plays the most crucial role. When it approaches twice the kinematic viscosity pressure rises tremendously and increases rotation by many folds but it does not lead to any discontinuity. This has been speculated as the genesis of dust devils. Even practically this is observe quite often.

Chapters 5 gives general solutions to many approximately explored results. The foremost conclusion drawn in this chapter is that viscosity, which is practically quite low in atmospheric vortices, plays a crucial role in the dynamic of whirlwinds. A nonviscous whirlwinds cannot exit.

Chapters 6 gives a more generalized solution for tornado dynamics considering all the velocity components also dependent on the height. In Burgers model, which is less general than this model has unbounded solution for radial and vertical velocity components. Such unboundedness are no more in this model of flow dynamics.

In the final chapter which is **7**th one in the thesis investigates cyclone, the largest atmospheric vortex. A general solution in term of viscosity has been attempted in order to identify the regions for rapid intensification. A similar investigation by considering the linearized viscosity has reported the presence of double exponential terms in the model for azimuthal velocity. The same has been identified as the region for the generalised viscous term. The model has been constructed by employing involved perturbation techniques.

Some more chapter wise result are as follows:

Chapter 3

- The radial pressure gradient caused by the variation of temperature creates a whirlwind. Even when there are no radial temperature gradients, once a region with low pressure is created, it will help the whirlwind survive.

- A whirlwind scales up some height into the sky because there is a favourable pressure gradient in the vertical direction and its absence will let the whirlwind lose its growth and lead to its disappearance. The whirlwind can scale a good height only when the annulus thus formed is thick.

- The angular velocity will be uniformly zero if the innermost radius tends to zero. This means there is no whirlwind. This endorses the fundamental characteristic that there must be a zone of low pressure inside the whirlwind with no angular velocity.

- The axial velocity has two parts. One of them is due to the inner region of low pressure of the whirlwind. This plays a vital role in the whirlwind dynamics as predicted by the model and it characterizes all the phenomena similar to whirlwinds

- If the radial pressure difference between the outermost and innermost layers is larger, the whirlwind is thicker and consequently, it will last longer.

Chapter 4

- The main conclusions of the entire discussion in this chapter are associated with the inflow parameter c of the radial component of velocity without which no formation of a dust devil can be thought of.

- The azimuthal component has no discontinuity for $c \to 0$, ν or 2ν. However, in spite of the fact that $c \to 2\nu$ does not lead to any discontinuity in pressure, it rises enormously at once, almost as an explosion having different limits depending on the radial coordinate, in a very small neighborhood of $c = 2\nu$. This causes compression and accelerates the formation of dust devils based on conservation of angular momentum. This situation is probably a fluid dynamic root cause, i.e., the driving force for the genesis of dust devils.

Chapter 5

- For the zero axial pressure gradient, the core radius increases infinitely for viscous flow when $t \to \infty$; while for non-viscous flows, the core radius reduced to zero when $t \to \infty$.

- For the non-zero pressure gradient, the core radius stabilises when $t \to \infty$, if the flow is viscous but vanishes for inviscid flows. It leads to the conclusion that viscosity is a prime factor for a vortex motion to survive.

- Azimuthal velocity rises very sharp with the radius, soon reaches the peak at the core, but then gradually diminishes in magnitude at a fast rate and finally dies out.

Chapter 6

- The magnitude of the radial velocity increases to the maximum at the core but reverses the trend beyond and vanishes as it reaches the centre line. The magnitude reduces linearly with axial distance as per the supposition.

- At the core larger the Reynolds number, lesser is the velocity for moderate Reynolds number. For larger Reynolds number insignificant impact is observed. However, inside and outside the core, the trends are reversed, i.e., larger the Reynolds number, lesser is the velocity.

- As we move outwards from the axis, pressure increases but pressure decreases with height and drop of pressure from the circumference to the axis increases in magnitude with height.

- Pressure decreases with rising Reynolds number uniformly for all radial distances. This is an indication that quantitative difference in pressure is large between viscous and inviscid flows.

Chapter 7

- The existence of double exponential terms was discovered as the reason for linear viscosity. Similar terms are observed even for the general form of viscosity. Hence, it is concluded that double exponential terms accelerate the rotational motion irrespective of the form of the viscosity.

- The domain of analysis is split into two regions, one which is distinct in the sense that all the updraft in confined in this region only which entirely lies within the radius of maximum velocity and the other beyond it, which is without updraft, has only azimuthal velocity.

- Vertical pressure depends on time, viscosity and the radius of maximum wind. Within the radius of maximum wind, we observe that pressure ascends with height and the radial distance but drops with time and also when the Reynolds number is increased.

- The azimuthal velocity rises fast with time close to the ground, but this dependence diminishes at a height little above the ground.

- The azimuthal velocity is found to rise very fast with time near the ground, but reverse is the trend at a little above and becomes independent of time at high altitudes. It drops further with time at even higher altitudes.

Further scope of research

Atmospheric vortices are terrifically complex phenomena. The rich literature presenting investigation of their flow dynamics is not enough. The real whirlwind have been often idealized for sake of modelling hidden characteristics and the simulations done dealt with single aspects. An atmospheric vortex whether dust devil, tornado or hurricane, has not yet been successfully modelled as a whole. Some of the characteristics are definitely common but the properties differ due to vast differences in their structures. Uneven and consistently changing structure add to the woe. Non-linear forms of the governing equations are still a huge hurdle on the way to arriving at solutions.

For want of appropriate models, predictions for their occurrence have been difficult, which are necessarily required to save loss of lives and property. Augmentation of more reality to the existing solutions will help us come closer to possible predictions. New discoveries of mathematical tools for the solution of nonlinear equations governing motion could be of immense help. More and more observational and experimental statistics can substantiate validation of proposed model. Hugeness and might of the atmospheric vortices remain troublesome reasons in investigation. Therefore much more sophisticated and advanced engineering tools and devices need to be invented to overcome uncontrolled nature of such terrifying vortices. Continued investigations moving, maybe inch by inch, will definitely be able to reach new horizons of explorations and achievements. The mission must continue.

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