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Use of Biplane Grids for On-site Studies of Hurricanes

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Abstract

For the interactive study of a hurricane after its landfall, a fleet of remotely operated, identical vehicles is proposed to be stationed in its path. Each vehicle would support two biplane grids placed parallel to one another. The positions and orientations of the vehicles would be remotely controlled to steer the frontal area of each grid to be nearly perpendicular to the wind's direction. The paper discusses the expected role of the grids in affecting the mixing of different flow regimes of the hurricane and the decay of its power.

Keywords: Hurricane, Decay, Landfall, Biplane grids, Turbulence, Mixing, Remotely operated vehicles, Interactive study

1. Introduction

Tropical cyclones with different ranges of maximum wind speed have different names. The maximum speed for tropical depressions is 17 m/s or less. For tropical storms, wind speeds range from 18 to 32 m/s. At 33 m/s or more, severe tropical cyclones that are also called hurricanes or typhoons are produced (see Emanuel, 2003). A hurricane, typhoon, or severe tropical cyclone is a magnificent weather phenomenon that will be known primarily for its power of destruction until we develop ways to affect its dynamics and cause decay in its power. As reported by Anthes (1982), attempts to modify a hurricane before its landfall have been made in the past. Our approach is to conduct interactive studies of hurricanes after landfall in an effort to avoid the destruction of dwellings and other property by unusually strong hurricane winds.

In the literature, we find numerous studies of hurricanes at their landfalls. Anthes (1982) has discussed the major physical effects that cause the decay of a hurricane over land. Kaplan and Demaria (1995 and 2001) have developed empirical models for predicting the decay of tropical cyclone winds after landfall. Their 1995 decay model is based on the National Hurricane Center (NHC) wind estimates for storms that made landfall south of 37 degree N latitude in the U.S. from 1967 to 1993. Their 2001 decay model is based on the storms that made landfall north of 37degree N latitude in the U.S. from 1938 to 1991. Kaplan and DeMaria (2001) have also indicated that their 1995 decay model has been incorporated in the software for emergency management by FEMA (Federal Emergency Management Agency). Demaria et al (2005) have reported that starting from 2000, the effect of storm decay over land has been included in the NHC's Statistical Hurricane Intensity Prediction Scheme (SHIPS). For tropical cyclones that move over narrow landmasses, DeMaria et al (2006) have provided a modified decay model, which reduced the intensity forecast errors by up to 8% relative to the original decay model for several storms from 2001 to 2004. Schneider and Barnes (2005) have reported measurements and analysis for Hurricane Bonnie at its landfall. Bonnie made its landfall at the North Carolina Coastline on August 26, 1998.

Anthes (1982) provides a comprehensive literature-based account of the physics of tropical cyclones and methods of forecasting. Chan (2005) highlights the roles of flow speed, vorticity and latent heat in the tropical cyclone dynamics. He recognizes that with the development of the satellite technology, the predictions of tropical cyclone movement have improved significantly over the past two decades. In making this recognition, Chan has cited Goerss (2000), who notes the use of an ensemble of dynamical models for the predictions. In the official NHC estimates for the Atlantic Basin, the mean hurricane track error for 12 hour prediction was 56 km; since 1990, the 24 – 72 h forecast errors have been reduced by 50% (see Franklin, 2007).

The literature on a hurricane's dynamics after its landfall, including the prediction of its track, provides adequate knowledge for promoting research aimed at interactive in-field studies. For extending this knowledge, it appears worthwhile to explore different methods of physical interaction with hurricanes over land. As a method of physical interaction, this presentation proposes the use of biplane grids placed in the path of a hurricane to affect its dynamics and probably to stimulate its decay process. The following paragraphs present the known factors that affect the decay of a hurricane at its landfall; a conceptual configuration for placing biplane grids in a hurricane's path at its landfall; and the anticipated effect on the decay of hurricane power.

2. Hurricane's decay at its landfall

A relatively detailed account of a hurricane's structure is provided by Holland, Simpson and Simpson (2002) in the McGraw-Hill Encyclopedia of Science and Technology. A hurricane consists of a cloud-free eye encircled by an eye wall of clouds, which is surrounded by spiral bands of rain. Speeds of air flow are different in different regions. Highest speeds occur in the eye wall region. To gauge typical sizes of hurricanes, Emanuel (1991) notes that near the ocean surface the radius of high winds ranges from 10 to 100 km and the height of spiral bands of clouds and precipitation ranges from 3 to 15 km.

Anthes (1982) mentions three major physical effects leading to the decay of a hurricane over land. First is the reduction in evaporation as the storm leaves the ocean, which decreases one source of the hurricane's energy, that coming from the condensation of vapors. A second effect is that the land is cooler than the ocean, and thus the low-level air is cooled. The third effect is the increase in surface roughness which produces a corresponding increase in the drag. The roughness parameter over land is 30 or more times that of the ocean surface. Emphasizing that over land a hurricane has no increase in its power, Hayden (2006) declares that landfall is a death sentence for a hurricane. As an exceptional case study, however, Bosart and Lackman (1995) have identified the post-landfall re-intensification of Hurricane David in 1979. Emanuel (2005), in his discussion on post landfall decay of a hurricane, has included factors that can lead to the occasional rejuvenation.

3. Turbulence and mixing from a biplane grid

A biplane grid consists of a number of solid cylindrical rods placed parallel to each other and equally spaced in a plane (the first plane), with the same number of rods of the same size placed in a second plane that is parallel and close to the first one. Every rod in the second plane is perpendicular to those in the first plane. A nonturbulent flow, when it passes through such a biplane grid, would become turbulent. Pope (2000) has used the name "turbulence generating grid" for "biplane grid," and has provided a sketch that illustrates its mesh size. In routine studies, a grid is placed in a flow with its area being perpendicular to the flow direction; that area may be termed the frontal area. The turbulence research community has essentially used biplane grids in wind tunnels to study the behavior of homogeneous isotropic turbulence (see Comte-Bellot and Corrsin, 1966). Environmental engineers have also used biplane grids to affect mixing in fluids (see Liem and Smith, 1999). For a study of homogeneous turbulence in a wind tunnel, Tucker and Ali (1976) have used a perforated sheet instead of a biplane grid. For this study, however, we propose the use of a biplane grid.

If any fluid flow has turbulent and nonturbulent flow regimes, they are separated by a sharp interface known as the viscous super layer (see Pope, 2002 and Ali and Ibrahim, 1996). In a hurricane, we recognize an eye, an eye wall, and spiral rain bands as distinct flow regimes. Therefore, we expect that a hurricane includes both turbulent and nonturbulent flow regimes seperated by viscous super layers. Imagine a system of biplane grids of an effective mesh size smaller than a meter, and a frontal area of a few thousand sq m placed in the path of a hurricane at its landfall. In the flow subjected to passing through the grid system, the viscous super layers would tear apart and different flow regimes would get mixed. The grid-affected flow would become turbulent everywhere. The phenomenon of mixing would cause decay in the hurricane's power. Ordinarily, such mixing is limited to a small height from the ground. The presence of a grid would affect a relatively larger height of the flow. Therefore, we anticipate that by encountering a grid in its path, a hurricane would experience appreciable decay in its power.

4. Conceptual configuration of transportable biplane grids

Researchers of turbulent flows have used biplane grids in wind tunnels (see Pope, 2002). A wind tunnel typically has a confined flow. The fan or blower in a wind tunnel maintains the flow through the grid by overcoming its blocking effect. A grid placed in a hurricane would not have any walls or nozzles around it to capture and confine the flow. It would act as an obstacle for blocking the flow, and a significant fraction of the flow would tend to go around the grid instead of going through it. That might jeopardize the desired effect of the grid on the flow.

The proposed transportable grid configuration would consist of 200 identical but non-joined modules, which would be remotely controlled from a central station. A module would consist of two biplane grids placed parallel to each other on a truck trailer or specially designed vehicle. The length of each grid would be nearly the same as the length of the trailer. The height of the grid would not be restricted by the trailer dimensions. The space between the two parallel grids would be the same as the trailer width. For each grid, the proposed approximate dimensions of the frontal area are 10 m length x 10 m height, and the proposed mesh sizes for the front and rear grids are one meter and 0.75 meter, respectively. The space between the front and rear parallel grids would be 3 m. The proposed two-grid configuration is expected to have a smaller blocking effect than a single grid of the same effective mesh size. At any given location being traversed by a hurricane, the wind directions would vary with time. The orientation of each vehicle would be remotely controlled so that the airflow would remain nearly perpendicular to the frontal areas of the grids despite varying wind directions.

A vehicle, together with its grids, is a transportable module so that two hundred modules placed in a certain order make up the complete grid configuration at a target location calculated to encounter a predicted hurricane at its landfall. A driver moves each vehicle from its parking site to the target site, then the driver leaves and the vehicle's movement and maneuvers are thereafter remotely controlled. Each vehicle is equipped with sensors for prescribed flow parameters, so that the sensor signals serve as inputs for remote control of its orientation and movement. A few of the vehicles also accommodate measuring instruments and a data recording facility for study of the flows upstream and downstream of the grid configuration. Measurements of flow velocity, temperature, pressure, and humidity would be of primary interest.

5. Discussion

The mobile biplane grid formation comprised of 200 identical vehicles as non-joined modules, is proposed for on-site interactive study of hurricanes at their landfalls. The remotely controlled vehicle system would have sufficient maneuverability to allow each vehicle to be placed in the predicted hurricane track. The presence of the grid formation in a hurricane's path after its landfall would affect the flow through an area of 2 000 m width x 10 m height. Within 10 m height from the ground, the grid formation would capture the high-speed flow including certain parts of the hurricane's eye and its eye wall. We expect that mixing of different flow regimes in the grid-affected flow would cause a measurable loss in the hurricane's power. The proposed number of vehicles and grid dimensions are open to critical review and changes. For repeated use to study several hurricane landfalls over a few years, every vehicle would have both permanent structural features and non-permanent biplane grids. The biplane grid's geometry and configuration could be progressively evaluated and improved as needed.

The hurricane features that cause damage to dwellings are strong winds, water surges, thunder, and tornadoes. The use of a grid structure has a limited scope of addressing the strong winds at a hurricane's landfall. For the damage due to strong winds, Emanuel (2003) suggests that the amount of damage increases roughly as the square of the intensity of the storms, as measured by their maximum speed. The drags, which contribute to the hurricane's decay, whether due to ground friction or biplane grids, are also proportional to the square of the velocity of the flow stream. Therefore, the placing of a grid formation in the path of a hurricane at its landfall would cause appreciable decrease in the damaging effect.

The challenging tasks required in the conduct of the proposed field study include: (a) to adopt appropriate standards so that the configured modules or vehicles remain structurally stable in strong winds and their functions are not affected by a water surge; (b) to station the grid formation at such a location where the hurricane's eye wall must pass through it, which is highly challenging because the width of the grid formation is only 2 km, whereas a twelve-hour prediction would have a track error of 65 km; (c) to pre-determine the travel routes for moving the vehicles from their parking areas to the anticipated target sites; (d) to obtain the required permissions in advance from relevant administrative bodies for the movement and stationing of the vehicles to be used for interactive hurricane study; (e) to monitor and control the vehicles so that their respective grid frontal areas remain nearly perpendicular to the rapidly changing flow directions.

In support of his global weather control system, Hoffman (2002) hypothesizes that increased accuracy in prediction of atmospheric phenomena would enhance our ability to effectively control them by small perturbations. If we consider the presence of a grid formation of a few thousand square meter frontal area in the path of a hurricane as a small perturbation, then Hoffman's hypothesis encourages us to suggest that an appreciable decay in hurricane power due to the biplane grid is a realistic expectation. In these contexts, however, we must remain cautious that a perturbation of a complex organized flow field may also lead to instability and havoc. List (2004) says, "Interfering with tornadoes and hurricanes is hazardous, should it work, and is encumbered by possible legal challenges. It should await better scientific understanding." For the proposed grid configuration, we would minimize the risks by addressing the above-listed (a) to (e) challenges and requirements.

For measuring the performance of the grid configuration in aiding a hurricane's decay, the velocity data upstream and downstream of the configuration may be compared with the available decay models; for example, the 1995 and 2001 models by Kaplan and Demaria. Moreover, the measurements of different flow parameters upstream and downstream of the grid configuration will be valuable for learning about turbulence characteristics of the hurricane. Therefore, it appears worthwhile to conduct in-field studies to determine these characteristics and the effects of placing a biplane grid in the path of a hurricane at its landfall.

6. Conclusion

It is well recognized that a hurricane decays after landfall due to decreased evaporation, increased surface roughness, and the cooler surface of the land compared with that of the ocean. This study suggests that as an effective turbulence-generating or mixing device, the use of a biplane grid formation would augment the ground effect in causing the hurricane's decay.

The conceptual configuration of biplane grids, which is offered for conducting interactive on-site studies of hurricanes at their landfalls, has the potential to be considered by teams of researchers for further improvements and development. Besides the possibility of augmenting the decay process of hurricane power at its landfall, the interactive studies would generate valuable data on turbulence characteristics of hurricanes. It is understood that enormous challenges will be faced in performing the proposed experiments.

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