Wide area surveillance using ship wakes

The idea of wide area surveillance (WAS) is to develop and utilize sensors which give continuous views of expansive areas. The traditional camera/optical/acoustic methods can only monitor small area, while the WAS system can monitor an area several thousand times larger. WAS is usually provided by airborne/satellite-borne cameras which cover a wide swath of area. It was primarily used in the US as military surveillance technology for safeguarding the homeland. WAS technology is slowly making its way from the battlefields into the Police/Coast Guard Departments in all countries.

WAS footage has lower resolution than ordinary cameras, and individuals and vehicles appear as dots when the footage is viewed on a computer screen. India also has such advanced satellites like RISAT-1 and RISAT-2 with WAS limits of about 30 km and a resolution of 1 m. The synthetic aperture radar onboard the satellite allows RISAT-1 to collect data during both day and night, and in all weather conditions[1].

Here, the possibility of applying the same surveillance approach for maritime safety is examined. The ultimate purpose of this endeavour is to create a near real-time map of ship movements all over the world. According to Kelvin's study in 1800s, ships moving over the surface of undisturbed water set up waves emanating from their bow and stern[2]. The waves created by the ships are both divergent and transverse. This series of waves emanating from the moving pressure point is called a Kelvin wake. The divergent waves make an angle of 19°28′ with the wake axis[3]. Figure 1 shows the general nature of the Kelvin wake.

Figure 1. Wide area surveillance of ship wakes.

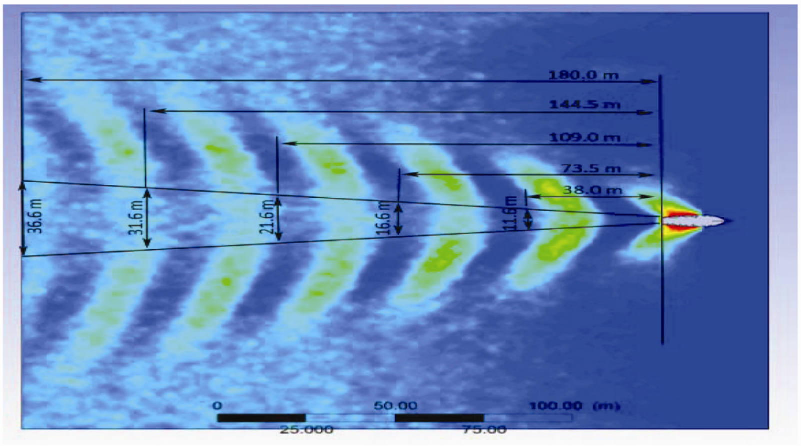

Figure 2. Wake for 20 m ship at 7.5 m/s (simulation output).

Recently, several researches have been conducted using Reynolds-Averaged Navier–Stokes (RANS) simulations standard tool for carrying out controlled studies of ships[4]. Along similar lines, we simulated the wakes of certain known vessels using computational fluid dynamics (CFD). Very realistic wakes of the ships can be simulated with CFD using the ANSYS FLUENT software. We have done the same to check and study in detail the wakes of ships. So, once we detect a wake, we use a parametric equation to reverse calculate the ship length, breadth and velocity from the characteristics of the wake. This reverse calculation is the thrust of this study.

We used the Hull model for numerical analysis. Simulations were carried out for ships of various sizes starting at 8 m length. Due to space constraint, here we only show the simulation for a ship of 20 m length (Table 1).

For performing the simulations, RANS solver ANSYS Fluent® which works on the finite volume method has been used.

- The ·igs file of the ship prepared using the AUTOCAD and Rhino three-dimensional modelling software.
- This file in ·igs format was imported in the ANSYS-ICEM CFD, where an unstructured smoothed mesh was created. For volume of fluid (VOF) work mesh was created in ANSYS Meshing by Cut Cell method.
- The boundary conditions were allotted to the respective surfaces.

Table 1. Principal dimensions of the representative ship

Length	20 m
Beam	5.59 m
Depth	2.94 m
Draft	0.588 m

Table 2. Coefficients in eq. (1)

Constants	Value
w_0	4
x_0	4
A	3.177
L/B	5

Table 3. Statistical errors in beam and velocity calculations

Lpp (m) and velocity (m/s)	Beam error (%)	Velocity error (%)
8, 3.6	1.2	4.1
9, 3.6	11.3	4.8
20, 6	5.34	6.14
20, 7.5	0.96	0.48
20, 9	3.68	4.18
40, 6	3.26	2.55
40, 7	0.34	6.37
40, 8	4.23	2.26
64, 7.5	1.17	2.84
320, 15	2.75	10
Mean error (%)	3.423	4.372

Lpp, Length between perpendiculars.

- Next the model (mesh) was imported into the solver ANSYS-FLUENT for numerical simulation.
- All settings were done in the solver; like selection of turbulence model, specifying the boundary conditions, specifying the material properties, the iterations settings, etc.
- After convergence, results were ported into the ANSYS-CFD POST where all the pressure plots, velocity contours, etc. were extracted.

CFD analysis using FLUENT software was done for the above ship. The width of the wake was measured as shown in Figure 2. From the width of the wake and L/B ratio of the vessel, we reverse calculated the breadth of the ship using the following equation[5]

$$W(x) = \frac{w_0}{\left(\frac{w_0 L}{B}\right)^{1/\alpha}} B^{\frac{(\alpha-1)}{\alpha}} X^{\frac{1}{\alpha}}, \tag{1}$$

where $W(x)$ is the wake width as a function of distance behind the ship (x (m) is the distance from the aft of the ship) (Table 2), α is a constant and B is the breadth of the ship. In this method, we get a best fit between $W(x)$ and x by adjusting the value of B accordingly[5] and reducing the mean square error.

Beam calculation: Wake calculation has been carried out for many ships and simulation output is shown here for a 20 m ship for a velocity of 7.5 m/s.

In this study we assume L/B ratio = 5. Note that $L/B = 5.0$ is a reasonable approximation for boats, ferries, cargo carriers, tankers, etc.

Velocity calculation: For the navy, another parameter of interest would be the velocity of a moving vessel. This can be determined by taking a line cut behind the ship and studying the static pressure there. From the static pressure variation, we can get the phase velocity of the wave which is the speed of advance of the ship. Since the waves are generated by the ship itself, this assumption is more or less accurate.

$$V_P = \sqrt{(\lambda g/2\pi)}.$$

where V_P is the phase velocity, λ the wavelength and g is the acceleration due to gravity.

Using the above results we have done calculations for ships of various sizes and velocities (Table 3).

In conclusion, we have applied certain empirical formulae for reverse calculating a ship's particulars from its wake signature. The wake itself was simulated using CFD modelling with ANSYS FLUENT. Simulations have been performed for many ships and for different velocities, and the results formulated. We obtain a statistical mean error over various ships of 3.4% and 4.3% for beam and velocity reverse calculations respectively. This is in the acceptable range and indicates the robustness of the method.

Though the study has been carried out using CFD modelling, the main purpose is to apply it to radar (SAR) images. In a real-case scenario, we will utilize the wakes in the radar images to reverse calculate using eq. (1) and detect the ship's particulars. This method of reverse calculation will aid in WAS programmes around the world. The method is promising, and though may not be an alternative to SONAR, it can be used as an aid to detect ships anywhere along the coastline in real time.

---

1. Sun, H., Shimada, M. and Xu, F., *IEEE Geosci. Remote Sensing Lett.*, 2017, **14**, 2013–2016.
2. Truesdell, *The Kinematics of Vorticity*, Indiana University Press, 1954.
3. Craik, A. D. D., *Annu. Rev. Fluid Mech.*, 2005, **37**, 23–42; Bibcode:2005AnRFM..37...23C, doi: 0.1146/annurev.fluid.37.061903.175836.
4. Tezdogan, T., Kemal, Y., Kellet, D. and Khorasan, P., *Ocean Eng.*, 2015, **97**, 186–206.
5. Zilman, G., Zapolski, A. and Marom, M., *IEEE Trans. Geosci. Remote Sens.*, 2004, **42**(10), 233–234.

Received 16 January 2018; revised accepted 8 March 2018

JAYANTA BARMAN[1]
ASHISH KUMAR[1]
H. V. WARRIOR[1,*]
P. A. MAHESWARAN[2]
HAREESH KUMAR[2]

[1]*Department of Ocean Engineering and Naval Architecture,*
Indian Institute of Technology Kharagpur,
Kharagpur 721 302, India
[2]*Naval Physical Oceanography Laboratory,*
Thrikkakara,
Kochi 682 021, India
**For correspondence.*
e-mail: warrior@naval.iitkgp.ernet.in