Could the accident of “Ever Given” have been avoided in the Suez Canal?

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Abstract. The paper analyzes the causes of the accident that took place on March 23, 2021 at 101 kilometers of the Suez Canal with the supercontainer ship “Ever Given”. The vessel lost control at the narrowest point of the transoceanic corridor. According to various sources, the possible cause of the accident was weather conditions. At the moment of passing through the Suez Canal, the vessel got into the area of a sandstorm with the increased wind speed and poor visibility. Sandstorms are frequent in the area. To avoid similar accidents, a quantitative analysis was performed to determine its causes. The analysis was undertaken based on solving the system of equations for mathematical model of a container ship with similar characteristics. The calculation was carried out according to well-proven methods with the involvement of databases for determining the hydrodynamic and aerodynamic characteristics. It has been established that a vessel with wind exposed area typical for vessels of the “Ever Given” type cannot be steered at wind speeds exceeding 12 m/s. In addition, a significant effect of the density of the air-dust mixture on the controllability of the vessel has been found. In the presence of an admixture of sand in the air, the vessel can lose controllability even at 9 m/s.

1. Introduction
On March 23, at 08.10 Moscow time, at 101 st kilometer of the Suez Canal, an accident occurred with the super-container ship “Ever Given”, which lost control in the narrowest point of this transoceanic corridor. There were 20 thousand containers on board.

Figure 1. Container ship “Ever Given” in the Suez Canal (https://www.marinelink.com/)

The vessel grounded with its bow tip and was turned in the canal so that it blocked traffic (Fig. 1). The Suez Canal was blocked for 6 days. Only on April 3, the ship was floated off. As Sky News
reported with reference to Reuters, after the tugboats managed to remove the stern and bow of the Ever Given from the shallows, the vessel began to drift in the fairway with strong winds with the risk of blocking the fairway again.

According to various sources, the possible cause of the accident was weather conditions. When passing through the Suez Canal, the vessel got into the area of a dust storm accompanied by an increase in wind speed and a decrease in visibility. Sandstorms in this area are frequent, and they are no less severe and fraught with consequences than snow charges at the Kara Gates and in the Vilkitsky Strait on the Northern Sea Route.

The air flow during a duststorm contains a large amount of soil particles, dust or small grains of sand from the Earth’s surface. The layer height can reach several tens of meters (Fig. 2). The movement speed ranges from 10 12 to 50 m/s.

The scientific literature contains a number of publications on testing a sand mixture in a wind tunnel [1–4] and in the environment [5–7]. In railway transport, considerable attention is paid to sandstorms since there is a risk of sand drifting on railway tracks and an increase in trains yawing [8–11]. An equally important problem is the effect of an abrasive mixture on building structures [12–15] and windmills [16–17]. However, calculations showing the effect of wind on a ship have not been identified in the scientific literature.

![Image](https://public.wmo.int/)

**Figure 2.** Airflow during a sandstorm ([https://public.wmo.int/](https://public.wmo.int/))

A duststorm can last from several hours to two or three days. An accident similar to the one that occurred in the Suez Canal can occur in any other place and with any vessel having a sufficiently large relative wind exposed area (or wind area) moving under the influence of the wind. Therefore, the purpose of this work is to perform quantitative analysis to clarify the reasons for grounding. To do this, it is necessary to construct and solve a system of equations of a mathematical model of a container ship with similar characteristics.

### 2. Ships description and methods

#### 2.1 Characteristics of modern container ships

Container ships are a relatively young class of ships. The first container was transported in April 1956. Ships specializing exclusively in container shipping appeared with the development of the transport fleet. Over time, the number of containers transported by a ship in one voyage has increased. Since 2010, a fleet has been formed capable of transporting up to 24,000 TEU (20-foot containers) in one voyage. The main dimensions of the ten largest vessels are shown in Table 1. Ever Given is one of the ten largest vessels.
Table 1. Main dimensions of the 10 largest vessels

| Vessel                  | Length, L (m) | Width, B (m) | Draft, T (m) | Capacity, TEU |
|-------------------------|---------------|--------------|--------------|---------------|
| MSC Mina                | 400           | 61           | 13.8         | 23,656        |
| MSC Gulsun              | 400           | 62           | 16           | 23,756        |
| HMM Oslo                | 400           | 62           | 11.7         | 23,792        |
| HMM Algeciras           | 400           | 61           | 14.4         | 23,964        |
| Jacques Saadé           | 400           | 62           | 12.8         | 23,000        |
| Hong Kong               | 400           | 59           | 14.7         | 21,413        |
| Shipping Universe       | 400           | 59           | 14.4         | 21,237        |
| Antoine de Saint Exupery| 400           | 58           | 13           | 20,954        |
| Madrid Maersk           | 399           | 58           | 14.1         | 20,568        |
| Ever Given              | 400           | 58.8         | 16.1         | 20,124        |

The increase in cargo capacity is provided, in particular, by increasing the length of the vessel. This fact is illustrated by the graph shown in Figure 3. The graph demonstrates the dependence of vessel lengths on the number of containers transported, which covers all existing types of container ships. Red dots mark vessels capable of carrying more than 10,000 containers.

![Figure 3. Cargo capacity of container ships of various lengths](image)

Cargo packed in containers can be transported on the upper deck, which inevitably leads to an increase in the wind area. The dependence of the increase in the wind area for ships of different cargo capacity is shown in Figure 4. As follows from the given data, container ships up to 270 meters long, capable of carrying up to 5,000 TE, have a wind area of up to 10,000 m². The wind area of a 400-meter container ship is almost twice as large and amounts to 18,000 – 20,000 m².

![Figure 4. Wind area for ships of different cargo capacity](image)
The effect of wind on the parameters of the ship movement directly depends on the ratio of the areas of the above-water and underwater body. The presence of deck containers significantly increases the wind area of the vessel. For the considered family of container ships, the ratio of the areas of the above-water and underwater parts of hull can reach 3.2 (Figure 5).

![Graph showing the ratio of above-water and underwater hull areas of container ships of different cargo capacity](image)

**Figure 5.** Ratio of above-water and underwater hull areas of container ships of different cargo capacity

Thus, with an increase in cargo capacity, wind impact on the parameters of movement increases significantly.

### 2.2 Navigation area characteristics

The vessel movement safety in a confined water area is determined not only by the maneuverability of the vessel and meteorological conditions but also by the characteristics of the area under consideration: the width and depth of the fairway, its tortuosity, the presence of a current, etc.

Safe steering assumes that the vessel heading angle coincides with the tangent to the navigable axis of the fairway. On a straight section of the fairway, the heading angle must coincide or be close to the centerline of the fairway. This means that the main condition for safe navigation is the extremely low vessel angular velocity or its complete absence.

![Satellite photo of the Suez Canal](image)

**Figure 6.** Satellite photo of the Suez Canal ([https://ru.wikipedia.org/](https://ru.wikipedia.org/))

The Suez Canal has long straight sections in the accident area (Figure 6). The safety of passing through it requires restrictions on the angle of the vessel deviation from the fairway axis, which is determined by the capabilities of the steering device.

Indeed, the guaranteed depth of the Suez Canal is 24 meters, and the width at a depth of 11 meters reaches 225 meters. Therefore, a vessel less than 200 meters in length should not experience any difficulties during its passage. The turn of the 400-meter vessel by only 40 degrees completely blocks the canal, which happened on March 23, 2021.
3. Results

Impact of wind on a container ship movement in the Suez Canal. In the absence of accurate information about the vessel “Ever Given”, an approximate estimate of the traffic parameters was made, for which information typical of the vessels of this class was used. The main dimensions of the design vessel are given in Table 2.

| Table 2. Main dimensions of design vessel |
|------------------------------------------|
| maximum length, m                        | L_{oa} 399 |
| length between perpendiculars, m         | L_{pp} 376.2 |
| Width, m                                 | B 59 |
| Draft, m                                 | T 16 |
| coefficient of fullness of displacement  | C_b 0.682 |
| rudder area, m^2                        | A_R 54.2 |
| rudder depth, m                         | h_R 9.1 |
| propeller diameter, m                   | D_p 9.1 |
| wind area per frame plane, m^2          | A_x 6,780 |
| wind area per centerline, m^2           | A_y 20,135 |

The design vessel was equipped with two semi-balanced rudders installed behind the propellers. The maximum rudder angle deflection was 35°. In the calculations, it was assumed that the ship moved along the fairway axis at a constant apparent wind angle. The rudder angle provides a straight-line motion of the vessel with zero angular velocity. The aerodynamic force and the aerodynamic moment proportional to the relative wind square velocity, air density and wind area. The hydrodynamic force and hydrodynamic moment proportional to the square of the ship’s speed, water density and the area of the underwater part of ship hull.

The equations were written in the body coordinate system (Figure 7). The relative wind angle was also determined in this coordinate system.

![Figure 7. Body coordinate system](image)

The equations of steady motion reduced to dimensionless form are shown below.

\[ C_x \cdot \bar{V}^2 + \frac{k_p(j_p)^2}{J_{pp}^2} \cdot \frac{2D_p^2}{L^2} \cdot \bar{z}_p + C_z A_x \cdot \frac{D_p}{\rho} \cdot \left( \frac{V_w \cdot \cos(\gamma) + \bar{V} \cdot \cos(\beta)}{V_0} \right) \cdot \frac{A_x}{L^2} = 0 \]  \hspace{1cm} (1)

\[ C_y^\beta \cdot \beta + C_y^\beta \cdot \beta^2 + f(j_p) \left( \frac{2\pi}{I+2(A_R/h_R)} \right) \cdot \frac{A_R}{L^2} \cdot \delta \cdot \bar{z}_p + C_y A_y \cdot \frac{D_p}{\rho} \cdot \left( \frac{V_w \cdot \sin(\gamma) + \bar{V} \cdot \sin(\beta)}{V_0} \right) \cdot \frac{A_y}{L^2} = 0 \]  \hspace{1cm} (2)
\[ C_{m}^{\beta} \cdot \beta + C_{m}^{\beta \beta} \cdot \beta^{2} + f \left( I_{P} \right) \left( \frac{2 \pi}{I + 2 \left( A_{R} / h_{R} \right)} \right) A_{R} \cdot \delta \cdot I_{R} \cdot z_{r} + C_{m A} \cdot \frac{\rho_{w}}{\rho} \left( \frac{V_{w}}{V_{0}} \cdot \sin(\gamma) + \sqrt{V_{0}} \sin(\beta) \right)^{2} \cdot \frac{A_{R}}{L T} = 0, \]  

(3)

where \( C_{x}, C_{y}^{\beta}, C_{m}^{\beta}, C_{m}^{\beta \beta} \) are hydrodynamic coefficients, \( C_{xA}, C_{yA}, C_{mA} \) are aerodynamic coefficients, \( k_{p} \) is propeller thrust ratio, \( J_{p} \) is advance ratio, \( D_{p} \) is propeller diameter, \( L.T \) is vessel length and draft, \( A_{R} \) is rudder area, \( h_{R} \) is rudder depth, \( \delta \) is rudder angle, \( V_{w} \) is wind velocity, \( V = V / V_{0} \) is non-dimensional ship speed, \( \beta \) is drift angle, \( \gamma \) is relative wind angle, \( \rho_{w} \) is air flow density, \( \rho \) is water density.

To assess the hydrodynamic and aerodynamic coefficients, the databases are usually used in the calculation methods of the university. The calculated values were the required rudder angle \( \delta \), the drift angle \( \beta \) and non-dimensional ship speed \( V = V / V_{0} \). The calculation results are shown in Figures 8a and 8b.

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**Figure 8.** Results of calculating steady motion parameters

It follows from the graphs that when the wind speed exceeds 10 m/s, the required rudder shift angle exceeds 35°, which leads to the impossibility of providing sufficient control on the vessel. The wind begins to increase the heading angle unpredictably until the boat finds a balance position. This usually occurs when the relevant wind angle is in the range from 70°–80° up to 120°. In the event of an
accident of the vessel “Ever Given”, the turn about the center of ship gravity was completed when the turn was 40° relative to the fairway axis as a result of the bowing of the bow on the canal wall, after which the turn of the vessel under the influence of the wind continued being relative to the point of contact until the vessel rested to the opposite bank by the afterend.

4. Discussion

Influence of air density on the parameters of the vessel steady motion in the canal. As noted earlier, while passing through the Suez Canal, the vessel got into the area of a sandstorm accompanied by an increase in wind speed. The air flow during a sandstorm contains a large amount of soil particles and dust. Obviously, the density of such a suspension is greater than the density of the usual flow generated in the wind tunnel when determining the aerodynamic characteristics of the body.

In the wind handling calculations above, the increase in air density was not considered. Obviously, an increase in air density should lower the threshold values for safe wind speed.

To assess the effect of air density, the calculations according to equations (1)–(3) were repeated for density values twice and three times higher than normal values. The results of determining the required rudder shift angle for a vessel moving along the canal with a wind of 9 m/s and with different air densities are shown in Figure 9. A significant effect of air density is obvious.

Density doubling leads to an increase in the required rudder angle almost to the maximum permissible values. A threefold increase in air density leads to a loss of ship control even with a wind speed of 9 m/s.

Figure 9. Value of required rudder angle for the wind of different density

It follows from the graph that the presence of a sandy suspension in the air can impair the maneuverability of the vessel and lead to loss of control even at a safe wind speed of 9 m/s.

5. Conclusion

According to the results of numerical studies, a possible cause of the accident was a wind of significant speed, whose effect was aggravated by a significant increase in the density of the air-dust mixture. The true cause of the accident was loss of control and subsequent unpredictable vessel behavior. The only way to avoid the accident was to predict the wind speed and prohibit the ship from entering the Suez Canal if there was a danger of a sandstorm.

Such storms can be observed in the southeast of the Rostov and Volgograd regions and on the territory of the Astrakhan region, which can cause accidents when vessels with a developed superstructure or with cargo on the upper deck move along the inland waterways of the South-East of Russia. As the above estimates show, the effect of airflow density is a serious problem.

Considering the large number of constructed container ships of this type, it can be assumed that similar accidents under analogous circumstances may be repeated. Similar cases can take place in any other confined water area in the absence of aerodynamic shadows for ships with a large ratio of the areas of the above-water and underwater bodies. In addition, such studies are of great practical
importance for the development of unmanned navigation [18-20]. When calculating the assessment of the maneuver, it is necessary to consider the change in air density during sand or dust storms.

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