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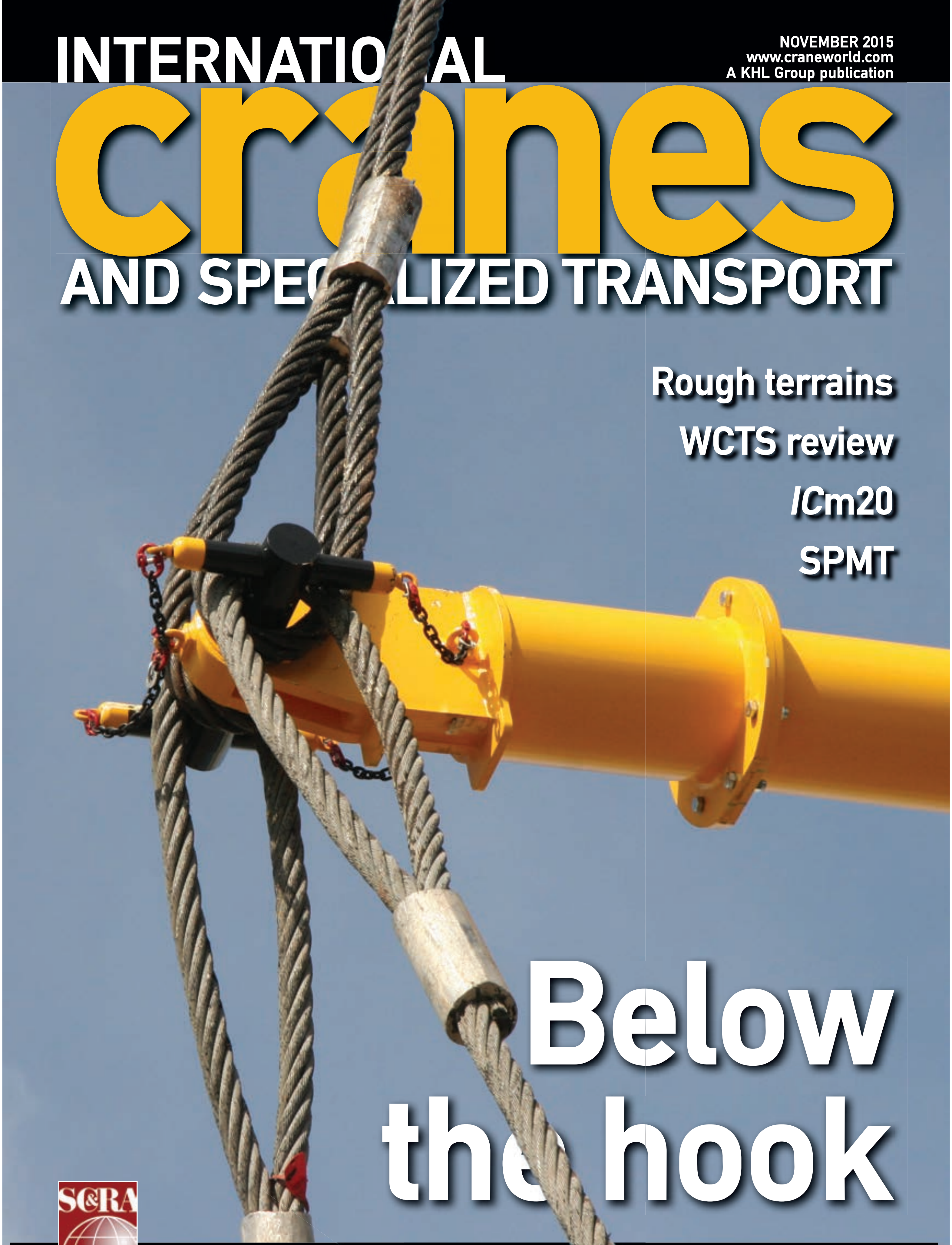
INTERNATIONAL cranes AND SPECIALIZED TRANSPORT



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S&RA OFFICIAL MAGAZINE

THE MAGAZINE FOR EQUIPMENT USERS AND BUYERS

Buoyancy and density

Understanding buoyancy is important for anyone involved in roll-on and roll-off operations in the specialized transport sector of the industry. MARCO VAN DAAL explains it and the practical implications

Most of us transport guys, at some point, are faced with performing a ro-ro operation. Either rolling a load from land onto a barge or from barge onto land. Of the multitude of barge types, supply barges and flat top barges are most frequently used for such operations. Supply barges are self propelled and are generally used to shuttle goods between shore and offshore locations. Flat top barges are generally not propelled but rather manoeuvred by tugboats. When driving from solid ground onto a floating object, different laws of nature apply, the most important one being Archimedes' Law.

Archimedes was a physicist from Syracuse, Italy, who lived from 278 BC until 212 BC. He is mostly known for his hydrostatics principles (buoyancy). These principles have not been challenged in more than 2,000 years and are still used in everyday life.

In its simplest form, Archimedes Law states that a body immersed in a fluid experiences a buoyant force equal to the weight of the fluid it displaces. In popular terms, if an object is immersed in fresh water and it displaces 1 US gallon (3.78 litres) of water, the force of buoyancy equals 8.33 pounds (3.78 kg).

In the very first article of The Knowledge (July 2013) we briefly touched base on Archimedes Law. This article goes a bit deeper as a preparation for next month's article.

A bit of theory: how did Archimedes prove this principle.

Review Figure 1, it shows the side view of an object immersed in a fluid. The arrows indicate the pressure (direction and magnitude) of the fluid onto the object. The arrows at the bottom are bigger/longer than the arrows on the top as the object's bottom is deeper in the fluid and therefore subject to a higher pressure. This is expressed with the formula $P = \rho * g * h$ where:

P is the pressure in kN/m^2 (or a conversion to Pascal or bar or PSI)

ρ is the fluid density (pronounced rho) in kg/m^3

g is the Earth's gravity expressed in m/s^2

h is the depth of the object in the fluid in metres.

As the pressure on the bottom of the object is larger than on the top of the object there is a resulting pressure facing upwards, this is the buoyancy principle.

Note that the pressures on each side of the object cancel out due to equal direction and magnitude and, therefore, there is no resulting pressure either in left or right direction.

To determine the magnitude of the buoyancy force Figure 2 helps, again showing an object immersed in a fluid.

As previously stated, the pressures P_3 on each side of the object cancel out and are of no influence on the buoyancy force. The pressures P_1 and P_2 can be written as follows:

EQUATION 1

$$P_1 = \rho * g * h_1 \qquad P_2 = \rho * g * h_2$$

The forces F_1 and F_2 that results from these pressures can be written as follows:

EQUATION 2

$$F_1 = P_1 * A_1 \qquad F_2 = P_2 * A_2$$

The difference between F_1 and F_2 is the buoyancy force F_b as follows:

EQUATION 3

$$F_B = F_2 - F_1$$

If we substitute F_1 and F_2 in equation 3 with the equation 2 we arrive at the following:

EQUATION 4

$$F_B = F_2 - F_1 = P_2 * A_2 - P_1 * A_2$$

Further substitution of P1 and P2 with equation 1 gives the following:

EQUATION 5

$$F_B = \rho * g * h_2 * A_2 - \rho * g * h_1 * A_1$$

Looking at Figure 2 again we can generalise the object's area and height into the following:

$$A_1 = A_2 = A \qquad h_2 - h_1 = h_{obj}$$

Substitute these generalisations into equation 5 gives the following:

$$F_B = \rho * g * A * (h_2 - h_1)$$
$$= \rho * g * A * h_{obj}$$

FIGURE 1

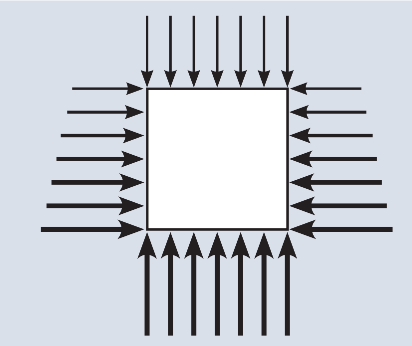
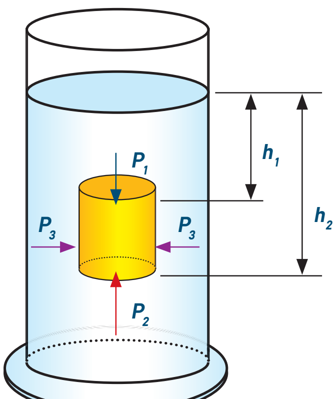


FIGURE 2

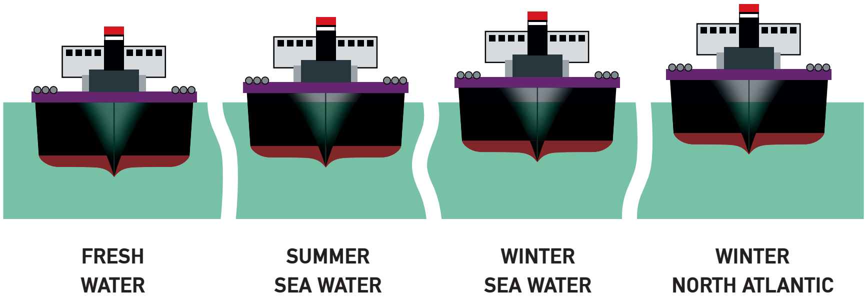


ABOUT THE AUTHOR

Marco van Daal has been in the heavy lift and transport industry since 1993. He started at Mammoet Transport from the Netherlands and later with Fagioli PSC from Italy, both leading companies in the industry. His 20-year plus experience extends to five continents and more than 55 countries. It resulted in a book *The Art of Heavy Transport*, available at: www.khl-infostore.com/books Van Daal has a real passion for sharing knowledge and experience and holds seminars around the world.

FIGURE 3

FIGURE 4



Now, an object's area (A) multiplied by its height (hobj) equals its volume (Vobj).

$$F_B = \rho * g * V_{obj}$$

This equation is known as Archimedes Law and expresses the (upward) buoyancy force *Fb* exerted onto an object immersed in a fluid. This force is determined by three variables:

1 Earth's gravity (*g*), this is pretty constant while on planet Earth. But if there would be lakes or oceans on, for example, the Moon the buoyancy force would only be a sixth compared to the same force on Earth as the gravity on the Moon (1.635 m/s^2 or 5.29 ft/s^2) is only a sixth of Earth's gravity (9.81 m/s^2 or 32 ft/s^2).

2 The volume of the submersed part of the object. When an object is completely underwater, its volume is at its maximum and so is the buoyancy force. If the object (let's take a barge or ship) is only partially submersed the buoyancy force increases as it takes on more cargo, or ballast water or supplies. The heavier the total weight of the barge or ship, the higher the buoyancy force. Obviously there is a limit to this as the vessel has to be kept afloat.

3 The density (ρ) of the fluid. This is an important variable. Its implication is that if the density of the fluid increases the buoyancy force increases. This is indeed exactly the case and can be seen on the hull of each ship where the load line or Plimsoll line is located, see Figure 3. The "F" stands for "fresh water", the "S" for "summer seawater". While carrying the same load, a ship has a shallower draft when sailing in summer seawater than when sailing in fresh water, hence the "F" mark being above the "S" mark on the hull. See also Figure 4.

Knowing that fresh water has a density of 1,000 kg/m^3 (58.9 lbs/ft^3) and salt water a density of 1,025 kg/m^3 (60.3 lbs/ft^3), a difference of only 2.5 %, you can see the enormous effect density has on buoyancy.

Newton's third law, action = -reaction, dictates that there has to be a force that counters the buoyancy force to keep the vessel in balance and prevent it from a continuous rise under the influence of only a buoyancy force. This counter force is the gravitational force indicated with *Fg*.

For any body in equilibrium (floating) the formula *Fb* = *Fg* is applicable.

The buoyancy force *Fb* can never be larger in value than the gravitational force Fg as the buoyancy force is a reactive force, it reacts to the gravitational force once an object is submersed in a fluid.

The gravitational force, however, *can* be larger in value than the buoyancy force. This means that the object is sinking and has not yet reached equilibrium. It will reach this equilibrium when it hits the bottom.

When a ship or barge is empty (it carries no cargo) it has a certain draft. This draft is caused by the weight of the empty vessel and the volume of water (either fresh or salt) it displaces. The buoyancy force and gravitational force are in balance *Fb* = *Fg*.

When loading cargo on board the vessel we all know that the draft will increase. This is because the combined weight is now higher and the gravitational force *Fg* is pulling on it. This increase in draft means that there is now more water displaced and therefore the buoyancy force *Fb* has increased. The draft will increase until the buoyancy force *Fb* has matched the gravitational force *Fg*. At that point a new equilibrium has been reached.

All about densities

Gravitational force is the force that pulls any mass down to Earth. The gravitational force does not discriminate, it pulls equally hard on all mass. But how do we explain that during an oil spill, oil is visible on top of the water and not the other way around. In popular terms we state that the lighter fluid floats on top of the heavier fluid. From a physics point of view this is an incorrect statement. In nature, things don't just happen for no reason. There must be a force that keeps the lighter fluid on top of the heavier fluid. The heavier fluid, water in this case, contains more mass per volume, it has a higher density than oil. Gravity pulls harder on the heavier fluid as there is more mass to pull on per volume. As the heavier fluid is pulled down, the lighter fluid is pushed away and ends up on top. This pushing away of the lighter fluid is caused by the buoyancy force.

The same principle applies to a hot air balloon. As the air inside the balloon is heated up, it expands resulting in a lower density, less mass per volume. The result is that the air outside the balloon has more mass per volume and gravity pulls this air down. Consequently the balloon containing less mass per volume is being pushed away and ascents.

The differences in densities is used in numerous every day processes, for example, a coloured multi-layered cocktail poured by an experienced bartender. He makes use of the densities by pouring the drink with the highest density first.

If the density of a fluid is high enough, for example, mercury at 13,534 kg/m^3 (845 lbs/ft^3) the buoyancy force will prevent a coin from sinking as there is much more mass per volume in the mercury than in the coin. See Figure 5. ■

FIGURE 5