# Wind and waves affect fuel consumption

Wind and waves affect fuel consumption through added resistance and because of reduced propulsive efficiency.

If the propulsion system has a considerable power margin it is possible to maintain constant speed.
The additional fuel consumption is determined by the increase in resistance and the decreasing propulsive efficiency at increasing propeller rpm or pitch.

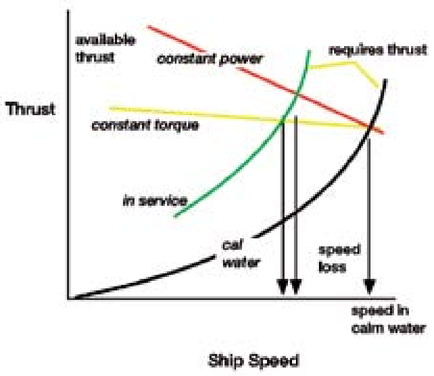
In case the propulsive system is already running at the maximum continuous engine rating the speed drops until the increasing thrust balances the total resistance. The additional fuel consumption is then given by the increase in trip duration, in which the decreasing propulsive efficiency plays a role.

In practice, constant power is typical for ships with controllable pitch propellers or diesel-electric propulsion systems. Due to the fact that diesel engines behave to some extent as “constant torque” devices, directly driven, fixed-pitch propeller systems are generally not capable of maintaining full power in the overload situation that occurs if the ship is slowed down by an additional resistance. Since no additional torque can be delivered the rpm reduces until equilibrium in torque is obtained.
The reduction in rpm and power increases the involuntary speed loss.

In this last case, the fuel consumption is determined by the trip duration and absorbed power, albeit that the trip duration is higher and the absorbed power in bad weather is lower than in the case with constant power.

The figure below shows the nature of the balance between the available and required thrust. The angle between the thrust requirements in calm water and the available thrust is a direct measure for the speed loss in lower waves. The larger this angle, the smaller the speed loss. Note that the angle is affected to some extent by the propulsion system. However, most of this characteristic is determined by the steepness of the required thrust curve that depends strongly on the hull form and the design speed. A ship with relatively low power will suffer more speed loss than a high-powered ship that is driven way up in the steep part of the curve.

*Speed – Thrust diagram*



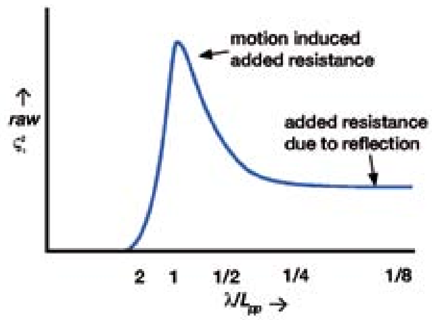

In cases where the sea keeping of the ship becomes unacceptable, for instance when there is risk of damage due to green water on the foredeck or excessive slamming induced vibrations, engine problems due to propeller racing, excessive rolling or course keeping problems, the master will reduce speed and/or change course. In many instances and in particular if the weather forecast is very bad, the master will be reluctant to accept the inevitable risks associated with sailing in bad weather. In these cases he will take proactive measures by deviating from the shortest route. This will increase the sailing time and consequently, the total fuel consumption over the route.

Both reactive and proactive measures lead to additional miles that, together with the lost time, will often motivate efforts to recover the delays.
But through these efforts fuel is wasted by sailing at uneconomically high speed levels.

## Magnitude of increase in fuel consumption

The impact of weather on shipping economics shows itself in the trip’s duration and by increased fuel consumption. Results of scenario simulations for relatively-fast ships on fixed routes, concentrating on the involuntary speed loss, suggest that the mean added resistance from wind and waves is somewhere around 5-10% of total resistance. Wind usually contributes around a third of this increase.

*Transfer function for added resistance in waves*




The above figure implies that in the situation where ship speed can be maintained, an increase in fuel consumption of 5-10% can be expected.

Normally the ship loses speed when there is insufficient power to maintain the speed. A resistance increase of 5-10% means a speed loss of approximately 2-5%. At constant power the increase in fuel consumption is directly related to the extra travelling time, therefore this increase is also in the region of 2-5%. The above simplistic scenario is of course, incomplete. The reactive and proactive measures of the master and attempts to recover delays will increase fuel consumption.

## Added resistance components

Experience from model tests shows that added resistance from waves is most prominent in waves from forward directions. Noteworthy is the fact that the values in waves from the bow quarter are some 25% higher than in head seas. The drift angle that is introduced in these wave directions is expected to contribute to this increase.

Added resistance in waves consists of two contributions, the motion induced resistance (related to heave and pitch) and the reflection induced resistance. The character of the related quadratic transfer function is shown in the figure below.

Numerical predictions of the added resistance by means of strip theory or 3D panel codes prove notoriously unreliable. This led MARIN to re-examine the model test results of 41 ships. For these vessels added resistance was measured in regular waves and an empirical model was derived.
Available information suggests that all theoretical and empirical predictions must be regarded with reserve because the scatter in the predictions remains relatively large. The latest information also suggests that bow flare may play an underestimated role in the added resistance in somewhat higher waves - an effect that is neglected in all prediction methods.

The direct contribution of the wind drag is mostly accounted for on the basis of the relative wind direction and relative wind speed. The indirect effect through a drift angle is usually neglected.
Model tests show that rolling, also when stabilised with fin stabilisers, does not show as a large component in added resistance. In waves from the stern quarter the active use of fin stabilisers does contribute to some additional drag, in particular for low-aspect ratio fins. The above mentioned evaluation method does not account for the use of stabilising equipment.

## Importance of design

Although the direct contribution of the added resistance from wind and waves may be limited, the designer has an influence on the fuel consumption.
The most important element is to build the ship in such a way that it can follow the most economical route at an economical speed. This implies adequate freeboard, limited bow flare deadrise, limited propeller ventilation, an engine that can cope with the required torque and torque variations and adequate roll stabilisation and course keeping.

A direct effect may be expected by avoiding full waterplane areas in the fore ship, by reducing the beam and by avoiding excessive deadrise in the bow flare. Of course, this can best be achieved by a design philosophy aiming at the best ship for its operational condition and not only for "contract condition".

**Source: MARIN report August 2008**