Chapter 7

Conclusions

In this thesis we have studied different non-homogeneous turbulent flows, both in the laboratory and in the ocean. The statistical description of these complex turbulent flows was based on the Extended Self Similarity (ESS). We have proposed a suitable methodology for non-homogeneous turbulence based on the analysis of the absolute energy transfer. The universality of Δ and the intermittency parameters β and μ were also analyzed. The intermittency parameter β, which is consistently defined for non-homogeneous flows, is estimated from the scale independent function $I(p/3)$, assuming that $I(p/3)$ follows the She-Leveque relation (3.43).

The main results for non-homogeneous turbulence in the laboratory experiments show that there is no range where the absolute scaling exponents ζ_p are constant. Almost everywhere, ζ_p depend on the separation distance ℓ.

Using the absolute values of the velocity differences, we show that the Extended Self Similarity is a convenient tool to measure the relative scaling exponents ζ_p/ζ_3 in non-homogeneous and non-isotropic flows. The way in which the third order scaling exponents modulate other scaling exponents seems a key issue in the physical interpretation of the use of Extended Self Similarity. It has also been confirmed, following Gaudin *et al.* (1998), that even in strong sheared and non-homogeneous regions Extended Self Similarity may be applied.

Deviations from the linear K41 law are observed in all laboratory experiments and in most locations in the flows. The relative scaling exponents ζ_p/ζ_3 are shown to be scale-independent but non-universal; they depend on the location in the flows in all experiments. The non-uniqueness of ζ_p/ζ_3 seems to be affected by the localness of the flow dynamics.

In fact, the intermittency is not uniformly distributed in the flow. There are regions with higher intermittency, where the dynamic is non-local, and regions with less intermittency, where the dynamics is local and turbulence is quasi-homogeneous. This indicates a close link between intermittency and non-homogeneity.

On the basis of laboratory measurements of cylinder wake turbulence, we confirm the methodology proposed by Babiano *et al.* (1997) and Babiano (2000) applied so far only to numerical experiments of two-dimensional turbulence.

On these complex flows, exhibiting a transition between two dimensional and three dimensional turbulence, even if the local scaling exponents $(\delta_\infty - \delta_0)$ and ζ_3 depend on the separation distance ℓ, the quantity Δ defined in relation (3.42) and its close approximation Δ^* show scale-invariant properties and seem to be universal. This behavior applies even if the energy cascade is anomalous. This seems a very important theoretical and empirical experimental result which could explain why the ESS property applies even in non-homogeneous and non-isotropic turbulence and at the same time give some physical interpretations of the compensation effect that the third order structure function scaling exponent has on the rest of the scaling exponents.

The energy spectrum is shown to be steeper than $k^{-5/3}$ in the locations near the cylinder. This indicates that the dynamics in these locations tends to be non-local due to the effect of the coherent structures. The use of the energy spectrum $E(k)$ in the non-homogeneous turbulence is not a good tool to define an inertial range, because we can easily find a range where the slope of $E(k)$ is scale-independent. In contrast, we cannot find any inertial range when plotting the absolute scaling ζ_p as a function of the separation distance ℓ. This means that the Fourier transform does not imply identical span of the power law range.

The intermittency parameter β was found to depend on the location in the flow and also on the order of the velocity structure functions in all the laboratory experiments. This important result demonstrates that the She-Leveque model is limited to the case of homogeneous turbulence. A comparison with the standard intermittency μ helps to identify the spatial variations of intermittency in non-homogeneous flows. On the other hand the results suggest that non-local and non-homogeneous flows cannot be totally understood by only using the ESS to measure the intermittency in non-homogeneous turbulent flows if the non-uniform energy transfer is ignored. There are regions where there are dominant local inverse cascades.

We also show the use of higher order structure functions and intermittency are useful in complex geophysically relevant non-homogeneous flows even if Taylor's hypothesis may not be applied.

Finally, we would like to stress the non-universality of ζ_p/ζ_3 apparent in non-homogeneous and non-isotropic turbulence but the invariant properties of Δ. This new invariant in three dimensional flows should be further studied and this work extended to analyze the behavior of Δ without ignoring the transversal velocity component and the pressure.

Future work should also investigate the dependence of Δ on other parameters such as the Reynolds number both in laboratory experiments and geophysical flows.