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# Scaling laws and intermittency in cryogenic turbulence using SHREK experiment

Swapnil Kharche, Michel Bon-Mardion, Jean-Paul Moro, Joachim Peinke, Bernard Rousset, Alain Girard

**Abstract** A fundamental study of normal helium turbulence (He- I) in von Kármán swirling flow generated with the help of one and only unique size facility called Superfluid High REynolds von Kármán experiment (SHREK) available at CEA-Grenoble is presented here. This study comprises of measurements of instantaneous velocity using the hot wire anemometry technique for three different configurations of the flow such as co-rotation, clockwise counter rotation (hereafter called contra rotation) and counter-clockwise counter rotation (hereafter called anti-contra rotation). The maximum Taylor's Reynolds Number,  $Re_\lambda$  for these measurements found to be up to 10000. A discussion on the aspect of intermittency is presented for the largest dataset available with the samples  $\mathcal{O}(10^9)$ . The probability density functions (PDF's) of the velocity increments are discussed with its skewness and flatness along with the exponents of structure function up to certain order. These effects of various quantities of turbulence such as scales of turbulence, dissipation and  $Re_\lambda$  with respect to applied forcing is discussed. The scalings laws already established for classical turbulence are explored based on the present experimental data in cryogenic turbulence.

## 1 Introduction and Motivation

Turbulence is a complicated physical phenomenon which comprises of the energy cascade through different sizes of eddies. The lack of high  $Re_\lambda$  flow experiments limits our understanding of turbulence. Experimentally, to study such highly turbu-

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lent flows has always been a challenging task for physicists. It is of utmost importance to validate each and every theoretical prediction to get a bigger and better perspective within the experimental framework. Based on such high  $Re_\lambda$  experiments we can build much more reliable turbulence models with much more accuracy which predicts the real behavior of turbulent flows.

The study of helium turbulence and its intermittency based on hot wire anemometry dates back to almost two decades with B. Castaing and his group[1]. Tabeing and his group[2] could reach  $Re_\lambda$  up to 2000 with the very limited experimental conditions. The SHREK experiment allows to perform similar experiments comparatively on a very large scale and also for variable experimental conditions which allows us to reach  $Re_\lambda$  upto 10000.

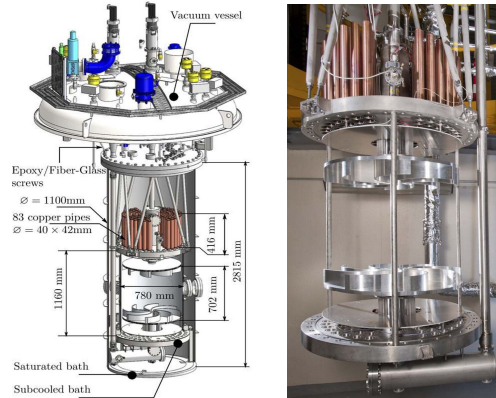
The main motivation of this experiment lies in the fact that we want to get one step closer to achieve very high Reynolds Number flow. The von Kármán flow basically is the flow between two rotating disks which is best suitable for generating highly turbulent flow, especially when disks are equipped with blades. As viscosity is the key parameter in any flow, to achieve higher Reynolds Number one could wish to have a flow of fluid having minimum viscosity; and so the liquid helium perfectly satisfies this requirement.

## 2 Experimental Setup

The experimental setup is very bulky and huge as shown in Fig.1. For the detailed dimensions and specifications of all parts of experiments one is referred to B. Rousset et al.[3]. From the figure it can be seen that the orientation of the blades on top and bottom propellers are not same. The curved shape of the blade on the disks causes a different sense of rotation. And so, you can generate different kinds of turbulent flows. It is necessary to establish some terminology regarding the rotation of blades in order to discuss the results in following sections. If both the turbines rotate in the same direction; it is Co-rotation configuration of flow. If the concave surface of the blades pushes the fluid then it is Anti-contra configuration of flow. On the other hand, if the convex surface of the blades pushes the fluid it is Contra configuration of the flow. Overall, if you look at the experiment from top view; the anti-clockwise rotation of any turbine is assigned a +ve sign and -ve sign for the clockwise rotation.

The experimental conditions inside the von Kármán cell were maintained at a pressure of 3bar and temperature of 2.2K, i.e. slightly above the superfluid transition. Referring to the P-T diagram of Helium, all these measurements were taken for the flow of Normal Helium(He-I). Although this experimental facility can also run using superfluid the results presented here are only limited to He-I. A home made hot wire made up of platinum of length 300 microns with a diameter of 1.2 microns was used during this experiment. The hot wire was fixed slightly above the center and 4cm away from the fixed wall of the von Kármán cell in order to avoid any boundary layer effects. The hot wire was operated using the constant temperature anemometry(CTA). A typical acquisition frequency of 50kHz was used with

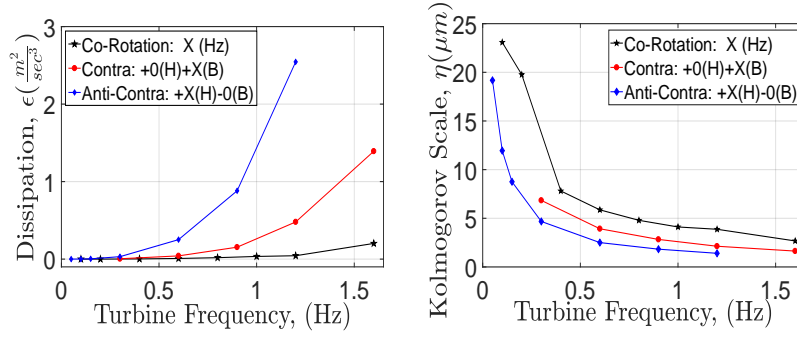
a 25kHz low pass filter. During data post processing, a 4<sup>th</sup> order low pass filter around 6-7 kHz was used in order to get rid of experimental noise. The hot wire was calibrated using the well known King's law of calibration[4]. A co-rotation configuration of flow was used in order to calibrate the hot wire assuming the solid body rotation was achieved inside the von Kármán cell during this flow configuration.



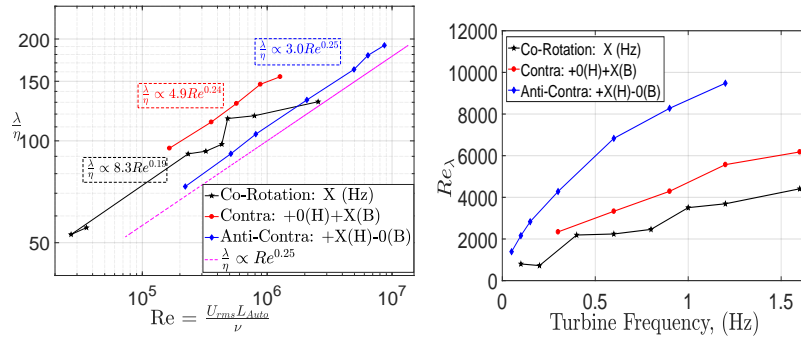
**Fig. 1** Detailed sketch of SHREK; Left: Dimentions used in SHREK for various parts; Right: von Kármán cell with the curved turbine blades[3]

### 3 Results and Discussion

The results presented here are discussed with respect to the applied forcing, based on the frequency of rotation of propellers, 'X' Hz. In anti-contra the bottom turbine is kept at rest while in contra the top turbine is kept at rest. Apart from this, a special case of contra configuration when both propellers are rotating: -0.12Hz(upper propeller, hereafter 'H') + 0.18Hz(lower propeller, hereafter 'B') is used to discuss the intermittency. The turbulent intensity ranges from 5 to 20% of the mean velocity, out of which is maximum for the anti-contra configuration. The integral length scale,  $L$  is calculated using the asymptotic value reached after taking the cumulative integration of the autocorrelation coefficient[5]. A Taylor's hypothesis has been used to convert time series into spatial scales. Fig. 2 shows the variation of dissipation,  $\epsilon(r) = -\frac{5}{4} \frac{S_3(r)}{r}$  and Kolmogorov scale,  $\eta = \left[\frac{\nu^3}{\epsilon}\right]^{1/4}$  calculated using the assumption of homogeneous isotropic turbulence (HIT) from 3<sup>rd</sup> order structure function,  $S_3$ [5-6]. Note that, the  $\epsilon$  in this figure is calculated based on the plateau in inertial range. The value of kinematic viscosity for He-I at present experimental conditions is  $\nu = 2.14 \times 10^{-8} m^2/s$ .



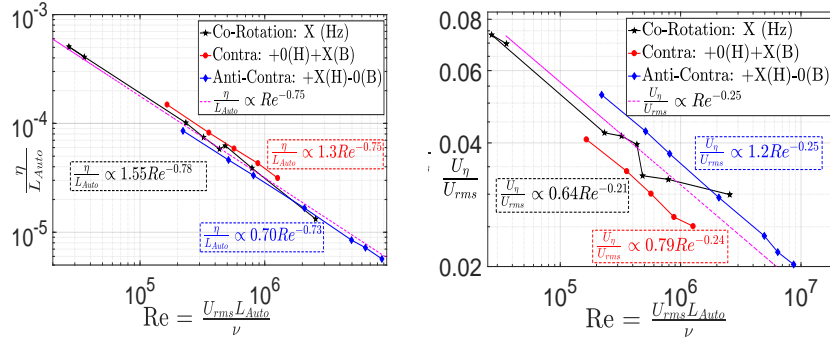
**Fig. 2** Left: Variation of dissipation with applied forcing; Right: Variation of Kolmogorov scale with applied forcing for different configurations of the flow [X: Turbine Frequency (Hz)]



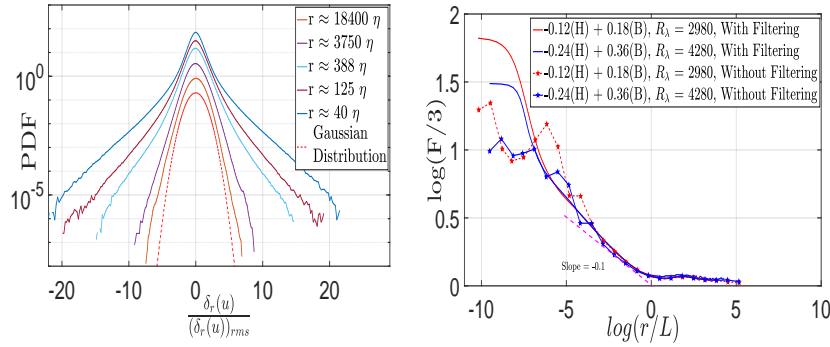
**Fig. 3** Left: Scalings of  $\frac{\lambda}{\eta}$  with  $Re$ ; Right: Variation of  $Re_\lambda$  with applied forcing for different configurations of the flow

Fig. 3 and 4 explores the typical scalings established for classical turbulence in case of present experimental data. In classical turbulence, scaling of  $\frac{\lambda}{\eta} \propto Re^{1/4}$ ,  $\frac{\eta}{L} \propto Re^{-3/4}$  and  $\frac{U_\eta}{U_{rms}} \propto Re^{-1/4}$  holds [6], where,  $Re = \frac{U_{rms} L}{\nu}$ ,  $\lambda = \sqrt{\frac{15\nu U_{rms}^2}{\epsilon}}$  and  $U_{rms}$  is the root mean square velocity of fluctuating component. The  $\frac{\lambda}{\eta}$  behaviour clearly shows its  $Re$  dependence and rules out an assumption of constant value[7]. Fig. 3 shows that the increase in the forcing results in smaller Taylor's microscale,  $\lambda$  and higher  $Re_\lambda = \frac{U_{rms} \lambda}{\nu}$ . It also shows that these scaling holds for the present experimental data with slightly different exponents for each different configuration. Fig. 5 shows the typical behavior of PDF's of velocity increment at different scales ( $\delta_r u$ ) [8] ranging from  $\eta = 8\mu m$  to  $L = 14.8cm$ , out of which the scales  $r \leq 300\mu m$  have shortcomings as a result of hot wire resolution. It also shows that the Flatness,  $F(r) = \frac{\langle (\delta_r u)^4 \rangle}{\langle (\delta_r u)^2 \rangle^2}$  of PDF's of  $\delta_r u$  increases for smaller scales. The same information can be interpreted in the form of Skewness,  $S(r) = \frac{\langle (\delta_r u)^3 \rangle}{\langle (\delta_r u)^2 \rangle^{3/2}}$ ,

which increases for larger scales. A typical slope of  $-0.1$  in the figure of flatness has been observed closer to the inertial range[9]. Fig. 6 shows the scaling exponent calculated for up to  $8^{th}$  order structure function using the approach of Extended Self Similarity(ESS)[10] which says that  $S_p \propto |\mathcal{S}_3|^{\zeta_p}$ , where,  $S_p$  is the  $p^{th}$  order structure function. A comparison of  $\zeta_p$  based on different models can be seen in this figure[11].



**Fig. 4** Left: Scalings of  $\frac{\eta}{L}$  with  $Re$ ; Right: Scalings of  $\frac{U_\eta}{U_{rms}}$  with  $Re$  for different configurations of the flow

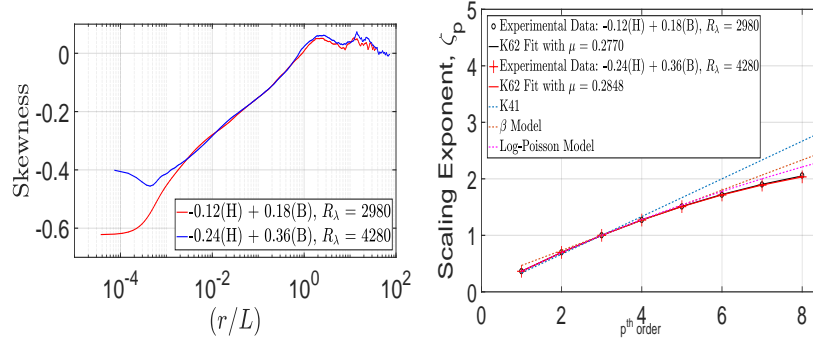


**Fig. 5** Left: PDF's of velocity increment for different scales; the curves are arbitrarily shifted for the sake of clarity, Right: Flatness of velocity increment PDF's as a function of scale

## 4 Conclusion and Future Scope

The various laws of scalings applicable to classical turbulence are validated in case of He-I turbulence at lower temperature. An investigation of the phenomenon of intermittency is done for the Normal Helium turbulence at lower temperature. This

study of intermittency supports the fact that this phenomenon at smaller scales is universal. An universal slope of flatness of the velocity increments near inertial range has been observed. The scaling exponents of structure functions are explored based on the assumption of extended self similarity. On a future note, similar experiments will be performed using different blades having different shapes to generate high level of turbulence. Similar experiments can be performed in future using Superfluid Helium (He-II). For this experimental data, it is planned to carry out the detailed Markovian analysis examining joint PDF's of velocity increments at different scales with the perspective of validating the integral fluctuation theorem.



**Fig. 6** Left: Skewness of velocity increment PDF's as a function of scale; Right: Scalings exponents of structure functions up to 8<sup>th</sup> order using ESS i.e.  $S_p \propto |S_3|^{\zeta_p}$

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