EVOLUTION OF ACTIVE GRID-GENERATED TURBULENCE

R. Jason Hearst & Philippe Lavoie
Institute for Aerospace Studies, University of Toronto, Toronto, Canada

INTRODUCTION

Modern vehicles and structures experience high-intensity, large-scale turbulence on a daily basis. However, simulating these conditions in an experimental environment is challenging. Traditionally, homogeneous, isotropic turbulence (HIT) is generated in a wind tunnel by deliberately perturbing the flow at the inlet of the test-section with an obstruction, such as a passive grid. Alternatively, high Reynolds number turbulence, resembling that in the atmosphere, may be simulated using a Makita-style active grid [6]. Makita's original design consisted of square wings mounted to rotating round rods oriented in a mesh pattern. The wings were mounted to each rod such that when all wings were perpendicular to the streamwise direction, there was 100% blockage. The rods of the grid were randomly rotated by stepper motors, thus creating a transient flow blockage. Functionally, when a single rod was actuated, all the wings along that rod moved together, hence the motion of adjacent wings was coupled. The motion of the grid generates turbulence that evolves downstream into high-intensity HIT. Makita's original grid produced Taylor microscale Reynolds numbers, $Re_\lambda = \langle u^2 \rangle^{1/2} \lambda / \nu$, approaching 400, whereas passive grids produce values of $Re_\lambda < 100$.

Hearst and Lavoie [3] introduced a new active grid constructed in a double-bi-planar arrangement. The grid consisted of two meshes, with the rotating wings mounted in an alternating fashion between the forward and aft meshes. In this way, the motion of adjacent wings was decoupled. Through this double-mesh design and by placing more rods across the grid span, a more random transient blockage was produced than attainable by previous grids.

Active grids are of particular interest because they are able to produce high Re_λ wind tunnel turbulence that can be used to approximate conditions similar to those experienced in the atmosphere. Previous active grid investigations have primarily consisted of parametric studies [3, 4]. In contrast, the present study focuses on the spatial development and decay of turbulent energy in the high Re_λ flow produced by the active grid.

EXPERIMENTAL SETUP

The active grid is composed of two bi-planar meshes of steel rods with diameter 6.35 mm, each mesh forming a 10 horizontal-bar by 15 vertical-bar pattern. The horizontal and vertical bars within a given mesh are separated by 1 mm, while the second bi-planar mesh is positioned 40 mm downstream of the first. The grid mesh length is $M = 80$ mm. The 254 wings of the grid are mounted to the forward and aft meshes in an alternating pattern such that half the wings are on one mesh and the remaining wings are on the other, see [3] for details.

Tests were conducted with the grid in one of two operational modes: (i) fully-random (FR) mode where each bar of the grid receives its own random signal independent of each other bar, or (ii) 10 correlated (10CL) mode where sets of 10 adjacent grid bars receive the same random signal. Table 1 describes the test parameters in terms of their operational mode and the wing rotational rates, $\Omega \pm \omega$, where Ω is the mean rotational rate and ω is the random allowable variation in the rotational rate (a top-hat distribution was used). In Table 1, tests identified with an 'S' were conducted with square wings (55 mm $\times$ 55 mm) and those identified with a 'C' used circular wings (diameter 55 mm). Tests 1, 2, and 3 were selected to provide a range of Re_λ values at a given freestream velocity, U, while test 4 was deliberately matched to test 3 in order to ascertain the phenomenological differences between the 10CL and FR modes.

Tests were performed in the closed-loop return wind tunnel at the University of Toronto Institute for Aerospace Studies. The wind tunnel test-section is 1.2 m wide, 0.8 m tall and 5 m long. Tests were conducted at $U = 10$ m/s using constant temperature hot-wire anemometry. Both single-wires and X-wires were used in order to determine $\langle u^2 \rangle$ and $\langle v^2 \rangle$, where lower-case letters represent turbulent fluctuations. The hot-wires were traversed in the streamwise range $30 \le x/M \le 55$, with measurements performed at intervals of $0.75M$.

Table 1. Test parameters and nominal values of decay rate and Reynolds number. $\langle \cdot \rangle_x$ represents an average in the streamwise direction.

	S1	S2	S3	S4	C2	C3	C4
$\Omega \pm \omega$ [Hz]	0.625 ± 0.375	3.0 ± 2.0	8.0 ± 7.0	8.0 ± 7.0	3.0 ± 2.0	8.0 ± 7.0	8.0 ± 7.0
mode	FR	FR	FR	10CL	FR	FR	10CL
m	1.26	1.32	1.18	1.32	1.34	1.21	1.15
$\langle Re_\lambda \rangle_x$	672	445	356	409	409	347	338

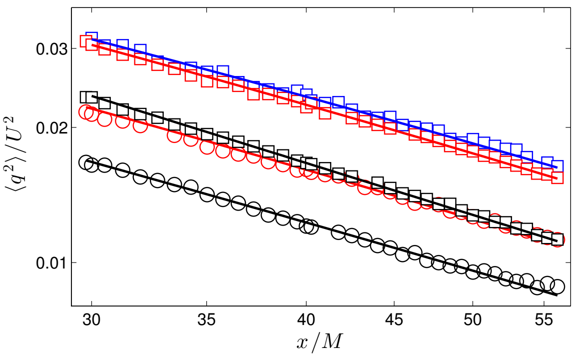

Figure 1. Decay of turbulent kinetic energy. S1 (□), S2 (□), S3 (□), C2 (○), C3 (○). S4 and C4 omitted to reduce clutter.

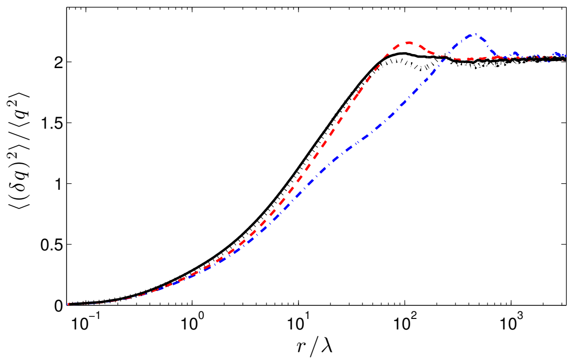

Figure 2. Normalised second-order structure function at $x/M = 40$. S1 ($- \cdot -$), S2 ($--$), S3 (—), S4 ($\cdots$).

INITIAL RESULTS

The turbulent kinetic energy produced by the active grid for all test cases and wing geometries follows the classical power-law decay behaviour, i.e. $\langle q^2 \rangle \sim (x - x_0)^{-m}$ where $\langle q^2 \rangle = \langle u^2 \rangle + \langle v^2 \rangle + \langle w^2 \rangle$ and $m \geq 1$, which one would expect for such a flow [2]. The exponent values presented in Table 1 were found to agree with classical grid turbulence results [1, 5, 7]. Nominal values of Re_λ are also given in Table 1. The decay of the turbulent kinetic energy and the corresponding power-law fits are shown in Figure 1. Figure 1 also demonstrates the well-documented [3, 4, 6, 7] trend that the turbulence intensity is inversely proportional to Ω.

The normalised second-order structure functions, $\langle(\delta q)^2\rangle/\langle q^2\rangle$, for S1, S2, S3, and S4 at $x/M = 40$ are shown in Figure 2. Several interesting phenomenological differences between the test cases are evident in this figure. First, $\langle(\delta q)^2\rangle/\langle q^2\rangle$ of S3 and S4 appear to be nearly identical, save the oscillations experienced by S4 near the plateau. Second, peaks of S1 and S2 in $\langle(\delta q)^2\rangle/\langle q^2\rangle$ imply periodicity in the turbulent energy. The test cases with the lowest Ω experience the strongest periodicity, and hence reducing Ω not only increases the turbulence intensity, but also adds an element of periodicity to the flow. These results are substantiated by a low-frequency peak in the v spectra which is dependent on Ω (not shown here).

OUTLOOK

The final study will focus on the effects of the various initial conditions produced by the grid on the high-order statistics of high Re_λ turbulence. The second-order structure functions offer a preliminary sample of the results that will be discussed. The final work will also investigate the periodicity induced by certain grid settings on the decay of turbulence and compare it to the passive grid work of Lavoie *et al.* [5], who also discussed the influence of periodicity on the decay of turbulence.

References

[1] G. Comte-Bellot and S. Corrsin. The use of a contraction to improve the isotropy of grid-generated turbulence. *J. Fluid Mech.*, **25**(4):657–682, 1966.

[2] W. K. George. The decay of homogeneous isotropic turbulence. *Phys. Fluids*, **4**(7):1492–1509, 1992.

[3] R. J. Hearst and P. Lavoie. A parametric study of high Reynolds number grid-generated turbulence. In *42nd AIAA Fluid Dyn. Conf.*, number AIAA-2012-2852, 2012.

[4] J.V. Larssen and W.J. Devenport. On the generation of large-scale homogeneous turbulence. *Exp. Fluids*, **50**(5), 2010.

[5] P. Lavoie, L. Djenidi, and R. A. Antonia. Effects of initial conditions in decaying turbulence generated by passive grids. *J. Fluid Mech.*, **585**:395–420, 2007.

[6] H. Makita. Realization of a large-scale turbulence field in a small wind tunnel. *Fluid Dyn. Res.*, **8**:53–64, 1991.

[7] L. Mydlarski and Z. Warhaft. On the onset of high-Reynolds-number grid-generated wind tunnel turbulence. *J. Fluid Mech.*, **320**:331–68, 1996.