ERCOFTAC Data Base

Testcase 39 - Leuchter: Rotating homogeneous turbulence in axisymmetric contraction.

The basic flow

Homogeneous turbulent flow in solid-body rotation is subjected to axisymmetric contraction with a nearly constant strain rate. The basic reference flow is defined by the following strain rate matrix:

$$(\lambda_{ij}) \equiv (\frac{\partial U_i}{\partial x_j}) = \begin{pmatrix} D & 0 & 0 \\ 0 & -D/2 & -\Omega \\ 0 & \Omega & -D/2 \end{pmatrix} \tag{1}$$

where D is the (constant) strain rate, and Ω the (time-dependent) rotation rate which varies with time according to

$$\frac{\Omega}{\Omega_0} = e^{Dt} = \frac{U}{U_0} \tag{2}$$

Ω_0 is the initial rotation rate before the strain is applied (at time t=0), and U_0 the corresponding axial velocity.

Experiment

The experiment is done in a facility in which solid-body rotation is created by means of a rotating duct equiped with a fine-mesh honeycomb and a grid turbulence generator, the meshsize of which can be adjusted. The rotating homogeneous flow is then accelerated in a contracting duct, the shape of which is defined by

$$\frac{R(x)}{R_0} = (1 + \frac{Dx}{U_0})^{-\frac{1}{2}} \tag{3}$$

$R(x)$ is the radius of the duct at position x and R_0 its initial value ($R_0 = 0.15m$); x is the axial distance from the initial section. The shape of the duct as defined by eq.(3) corresponds to a constant strain-rate D for non-rotating flow (and negligible boundary-layer effects). For rotating flow, the strain-rate on the axis is slightly increased (see ref.[2]), but it can still be considered to be constant over the major part of the duct.

Two contracting ducts of different length L, but with the same total contraction C have been used in the experiments:

- duct 1 of length L=1 m,
- duct 2 of length L=0.5 m,

The contraction C is defined by:

$$C = (\frac{R_0}{R(L)})^2 = 1 + \frac{DL}{U_0} \quad (4)$$

yielding for the strain rate: $D = (C-1)U_0/L$.

With $C = 4$ and the nominal axial velocity of $U_0 = 8m/s$, the corresponding strain rates are $D = 24s^{-1}$ for duct 1 and $D = 48s^{-1}$ for duct 2. The maximum initial rotation rate is fixed at $\Omega_0 = 48s^{-1}$, yielding a maximum rotation number $\omega_0 = \Omega_0/D = 2$ for duct 1 and $\omega_0 = 1$ for duct 2, see Table 1:

Table 1: Experimental conditions

	L	D	Ω_{0max}	ω_{0max}
duct 1	1 m	24 s^{-1}	48 s^{-1}	2
duct 2	0.5 m	48 s^{-1}	48 s^{-1}	1

For each duct two different experiments were made, one for $\omega_0 = 0$ (reference case of pure contraction), the second for $\omega_0 = \omega_{0max}$ (maximum rotation effects).

Measurements

The measurements are made with conventional hot-wire methods using DISA (DANTEC) anemometers 55M01 and crossed-wire probes of type P61. The statistical quantities are determined through digital data processing from 100×2048 simultaneous samples of both velocity components. Integral lengthscales are evaluated from frequency spectra via the Taylor hypothesis.

The flow is explored on the axis of the duct between the longitudinal positions $x/L = 0$ and $x/L = 1$ for duct 1 ($L = 1m$) and between $x/L = -0.25$ and $x/L = 1.25$ for duct 2 ($L = 0.5m$). The axial distance between successive measurement points is $\Delta x = L/16$, yielding a total number of 17 measurement points for duct 1 and 25 for duct 2, see Table 2.

Table 2: Explored flow domain

	L	$(x/L)_{min}$	$(x/L)_{max}$	$N_{meas.}$
duct 1	1 m	0	1	17
duct 2	0.5 m	-0.25	1.25	25

The measured quantities are:

- the axial mean velocity component U,

- the transverse mean velocity component V (negligeable compared to U),

- the variance of the fluctuating axial velocity component $\overline{u^2}$,

- the variance of the fluctuating transverse velocity component $\overline{v^2}$,

- the spectra of both velocity components,

- the lengthscales $L_u(= L_{11,1})$ and $L_v(= L_{22,1})$ deduced from the corresponding spectra.

The accuracy of the measurements is estimated to be of the order of one percent for the mean velocities and of the order of a few percent for the variances. Some larger dispersion of the measurements were observed for the integral lengthscales (not included in the data).

Initial conditions

The "nominal" initial conditions (at $x = 0$ and for $U_0 = 8m/s$, $\omega_0 = 0$) can be taken as follows:

* turbulent kinetic energy: $q^2/2 = 0.16m^2/s^2$,
* anisotropy: $(\overline{u^2} - \overline{v^2})/q^2 = 0.12$,
* dissipation rate: $\epsilon = 8.2m^2/s^3$,
* longitudinal integral lengthscale: $L_u = 5.8 \times 10^{-3}m$,
* transverse integral lengthscale: $L_v = 2.5 \times 10^{-3}m$,
* Taylor microscale: $\lambda = \sqrt{5\nu q^2/\epsilon} = 1.7 \times 10^{-3}m$,
* Kolmogorov lengthscale: $\eta = (\nu^3/\epsilon)^{1/4} = 0.14 \times 10^{-3}m$,
* microscale Reynolds number: $Re_\lambda = \sqrt{q^2/3}\,\lambda/\nu = 37$.

The experiments are strongly dominated by nonlinear effects, which are characterized by the linear-to-nonlinear time ratio

$$\tau \equiv \frac{t_L}{t_{NL}} = \frac{2\epsilon}{Dq^2} \tag{5}$$

τ is of the order two for duct 1 and of order one for duct 2. (Rapid distortion theory would require $\tau \ll 1$)

Presentation of the results

The results are disposed in four data sets corresponding to the nominal conditions indicated in Table 3. All the quantities are given in physical dimensions. Each data set contains 8 columns corresponding to the following quantities:

- **column 1:** longitudinal position $x(m)$,

- **column 2:** local strain rate D (s^{-1}), evaluated from $D = \partial U/\partial x$,

- **column 3:** local rotation rate Ω (s^{-1}), evaluated from $\Omega = \Omega_0 U/U_0$,

- **column 4:** axial mean velocity component $U(m/s)$,
- **column 5:** variance of the fluctuating axial velocity component $\overline{u^2}(m^2/s^2)$,
- **column 6:** variance of the fluctuating transverse velocity component $\overline{v^2}(m^2/s^2)$,
- **column 7:** trace of the Reynolds stress tensor $q^2(m^2/s^2)$, evaluated from $q^2 = \overline{u^2} + 2\overline{v^2}$,
- **column 8:** dissipation rate $\epsilon(m^2/s^3)$, evaluated from $\epsilon = -D(\overline{u^2} - \overline{v^2}) - \frac{1}{2}U[dq^2/dx]$.

Table 3: Nominal conditions of the data sets

data set	duct	U_{0nom}	D_{nom}	$\Omega_0/D = \omega_0$
1	1	$8m/s$	$24\ s^{-1}$	0
2	1	$8m/s$	$24\ s^{-1}$	2
3	2	$8m/s$	$48\ s^{-1}$	0
4	2	$8m/s$	$48\ s^{-1}$	1

Main references

[1] O. Leuchter, *Turbulence homogène soumise a des effets couplés de rotation et de déformation axisymétrique* , Internal ONERA Report 15/1145AY, September 1993

[2] O. Leuchter, A. Dupeuble, *Rotating homogeneous turbulence subjected to axisymmetric contraction* , Ninth Symposium on Turbulent Shear Flows, Kyoto, August 1993

[3] O. Leuchter, J.P. Bertoglio, *Non-linear spectral approach to rotating turbulence in the presence of strain* , Tenth Symposium on Turbulent Shear Flows, The Pennsylvania State University, August 1995