4th International PIV Challenge cases C and D

Contents

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In order to minimize your work and to save iterations between you and the steering committee, before discussing the different test cases some common points will be examined with particular regard to the format of the files that will be used to exchange data. If you have any doubts or comments please do not hesitate to contact Tommaso Astarita (astarita@unina.it) or Stefano Discetti (sdiscett@ing.uc3m.es).

1 General recommendation

The normal chain that enables to evaluate the 3D velocity field from the recorded images is the following:

1. Calibration;
2. Self calibration;
3. Tomographic reconstruction;
4. 3D correlation analysis.

After each step of the chain some **Input** and **Output** files are needed and in the following sub-sections this will be discussed in detail for each step. Some matlab scripts will be used to better explain the procedure.

All the input images will be in compressed 16 bits tiff files. A matlab script for reading the images is the following:

```
%read the image and convert to double (if needed)
InImg=double(imread('.\example.tif'));
%plot the image
imagesc(InImg);
```

1.1 Calibration

For the optical calibration normally a calibration target is moved inside the interrogation volume and a correspondence between the coordinates of some points in the physical space (x, y, z or $\underline{x}$) and the ones in the image plane (X, Y, or $\underline{X}$) is built. The contributors can choose between using standard calibration images (at different z values) or a list of coordinates of the target points in a comma separated values file.

1.1.1 Calibration images

The image file nomenclature will be X_Cal_camZ_OOOO.tif where X indicates the case acronym, Z the camera and OOOO the plane.

An example of calibration image is shown in the following figure. White (in the figure) spots indicate the calibration points in the xy plane. The distance between dots is fixed. As shown in the figure, two lines, starting from the origin, indicate the x and y axis. The x axis can be identified by the square that follows one of the lines.

1.1.2 Comma separated values file

The comma separated file is called X_Cal.csv and an example is:

x,y,z,Xcam0,Ycam0,Xcam1,Ycam1
-24,-32,-8,23.581,141.17,323.93,344.74
-24,-28,-8,28.217,220.01,316.65,421.25

A simple matlab script that reads the file is:

```
clear
%Read csv and plot points of first camera
M = csvread('X_Cal.csv',1,0);
plot(M(:,4),M(:,5),'.')
```
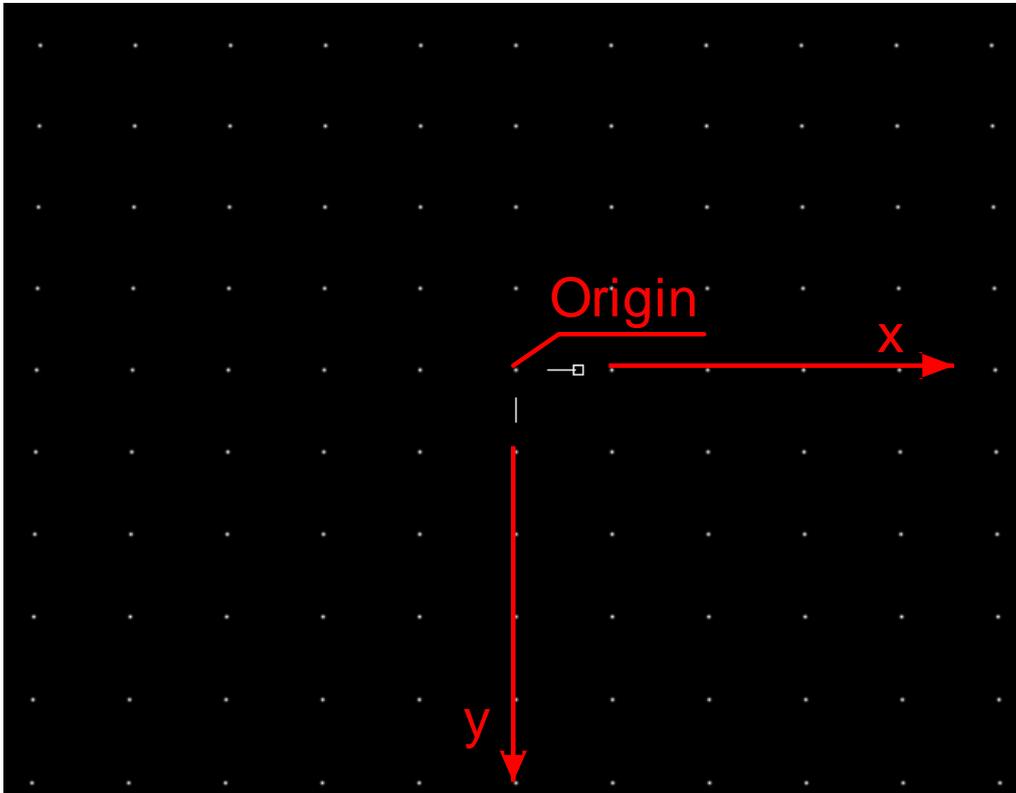

Calibration image.

1.2 Self calibration

The self-calibration will not be analysed in this PIV challenge therefore no errors are included in the calibration.

1.3 Tomographic reconstruction

The input file nomenclature will be X_camZ_OOOOa.tif where X indicates the case acronym, Z the camera, OOOO sequence number and, if needed, a/b for the first and second exposure, respectively.

The output of the tomographic reconstruction step will be provided by the contributors in a zipped hdf5 file (www.hdfgroup.org/HDF5). Since both PTV and algebraic (ALG) approaches can be used to perform the reconstruction, different types of information must be provided by the contributors as explained in the following sub-sections.

The output file nomenclature will be X_YYY_ZZZ_OOOOa.zip where X indicates the case acronym, YYY the contributor acronym, ZZZ can be PTV or ALG, OOOO indicates the sequence number and, if needed, a/b the first and second images. For example, for the test case C, reconstruction performed using ALG and sequence number equal to 1, the reconstructed volume names will be C_YYY_ALG_0001a.zip and C_YYY_ALG_0001b.zip for the first and the second exposure, respectively.

1.3.1 PTV

For the PTV approach a list of particle position and intensity, in single precision floating point, should be provided. A simple matlab script that writes the file is:

```matlab
% The filenames are:
FileName='X_YYY_PTV_OOOO';
h5_FileName=strcat(FileName,'.h5');
Zip_FileName=strcat(FileName,'.zip');

% x y z are the vector that define the physical coordinates of the particles
% Lev is the vector that define the intensity level of the particle
hdf5write(h5_FileName, '/x', single(x));
hdf5write(h5_FileName, '/y', single(y),'WriteMode','append');
hdf5write(h5_FileName, '/z', single(z),'WriteMode','append');
hdf5write(h5_FileName, '/Lev', single(Lev),'WriteMode','append');
% zip the hdf5 file and delete the original file
zip(Zip_FileName,h5_FileName);
delete(h5_FileName);
```

1.3.2 Algebraic approaches

For the ALG approaches a set of (16 bits) .tif compressed images of the xy planes should be provided.

The images can be written with:

```matlab
%%
FileName='X_YYY_ALG_OOOO_';
% W is the width (along the x direction) of the volume in voxels
% H is the height (along the y direction) of the volume in voxels
% D is the depth (along the z direction) of the volume in voxels
% Lev(H,W,D) is the array with the intensity levels on each voxel
for i=1:D
    Im=squeeze(Lev(:,:,i));
    Name=sprintf('%s%04d.tif', FileName,i);
    imwrite(Im,Name);
end
```

All the images should be finally zipped in a single file ('X_YYY_ALG_OOOO.zip).
Additionally the following data, which define the grid, should be provided in a .csv file (X_YYY_ALG_OOOO.csv):

x_Init[mm],y_Init[mm],z_Init[mm],dx[mm],dy[mm],dz[mm],W,H,D
0,0,0,0.4,0.4,0.4,1000,600,200

The first pixel (that in matlab has coordinates [1, 1]) of the first image "X_YYY_ALG_OOOO_0001.tif" has physical coordinates (x_Init, y_Init, z_Init), while pixel [2, 2] of image "X_YYY_ALG_OOOO_0002.tif" has physical coordinates (x_Init+dx, y_Init+dy, z_Init+dz).

1.4 3D correlation analysis

Data should be provided on a structured grid. In order to avoid ambiguities the grid is fixed and provided to the contributors in the file X_Grid.zip, where X indicates the case acronym. The grid points are generated, by the steering committee, with a simple matlab script similar to the following one:

```
% Grid spacing in mm. This is just an example and specific information
% will be given in Sections 2 and 3.
dx=.4;dy=.4;dz=.4;
xx=dx:dx:100;
yy=dy:dy:100;
zz=dz:dz:50;
% build the grid the first index correspond to y, the second one to x and
% the last to z
[x y z]=meshgrid(xx,yy,zz);
```

The file is a zipped hdf5 file and can be read with the following matlab script:

```
% The filenames are:
FileName='X_Grid';
h5_FileName=strcat(FileName,'.h5');
Zip_FileName=strcat(FileName,'.zip');
% unzip the hdf5 file
unzip(Zip_FileName);
% read the 3D arrays that define the grid
x=hdf5read(h5_FileName, '/x');
y=hdf5read(h5_FileName, '/y');
z=hdf5read(h5_FileName, '/z');
% delete the file
delete(h5_FileName);
```

The displacement field, on the provided grid, will be saved in a zipped hdf5 file and the output file nomenclature will be X_YYY_Var_OOOO.zip where X indicates the case acronym, YYY the contributor acronym, OOOO the sequence number. More details about the required data are reported in sections 2 and 3.

A simple matlab script that writes the file including the vorticity ω is:

```
% The filenames are:
FileName='X_YYY_Var_OOOO.zip ';
h5_FileName=strcat(FileName,'.h5');
Zip_FileName=strcat(FileName,'.zip');
% all data should be in single precision
hdf5write(h5_FileName, '/u',single(u));
hdf5write(h5_FileName, '/v', single(v),'WriteMode','append');
hdf5write(h5_FileName, '/w', single(w),'WriteMode','append');
hdf5write(h5_FileName, '/omegax', single(omegax),'WriteMode','append');
hdf5write(h5_FileName, '/omegay', single(omegay),'WriteMode','append');
hdf5write(h5_FileName, '/omegaz', single(omegaz),'WriteMode','append');
% zip the hdf5 file and delete the original file
zip(Zip_FileName,h5_FileName);
delete(h5_FileName);
```

2 Case C

2.1 Introduction
In the 3D scenario the spatial resolution is notoriously difficult to be predicted, as it depends on several parameters. Among the others, the particles concentration and the reliability of the algorithm for the reconstruction of the 3D particles distribution play a key role. Generally a compromise is required between dense particles distributions and sufficiently accurate reconstruction. To date, the trade-off is left to the personal experience of the experimenter. The purpose of the Test case C is to assess the performances of the reconstruction and processing algorithms in terms of final spatial resolution and accuracy.

2.2 Technical Information

The test case is performed on synthetic images of a complex flow field, composed of a set of 3D vortices with different wavelengths and amplitudes, a periodic pseudo-jet (the displacement field is not everywhere divergence free) and constant displacement zones. Projection images of 4 cameras are provided to the participants for several values of the particles concentration.

The optimization of the particle image density in terms of maximum spatial resolution with minimum loss of accuracy is the main challenge of the Test case C. The contributor should choose the best, from his point of view, particle image density and completely process only one set.

The dataset is generated with the following conditions (the volume is centred in the origin):

Volume size:	48 x 64 x 16 mm^3 (960 x 1280 x 320 vox @ 20vox/mm^*)
Particle image diameter:	~ 2.5pixels
Particle image density:	ranging between 0.01-0.15 particles/pixel

[*] Suggested resolution but the choice of the resolution value is left open to the contributor.
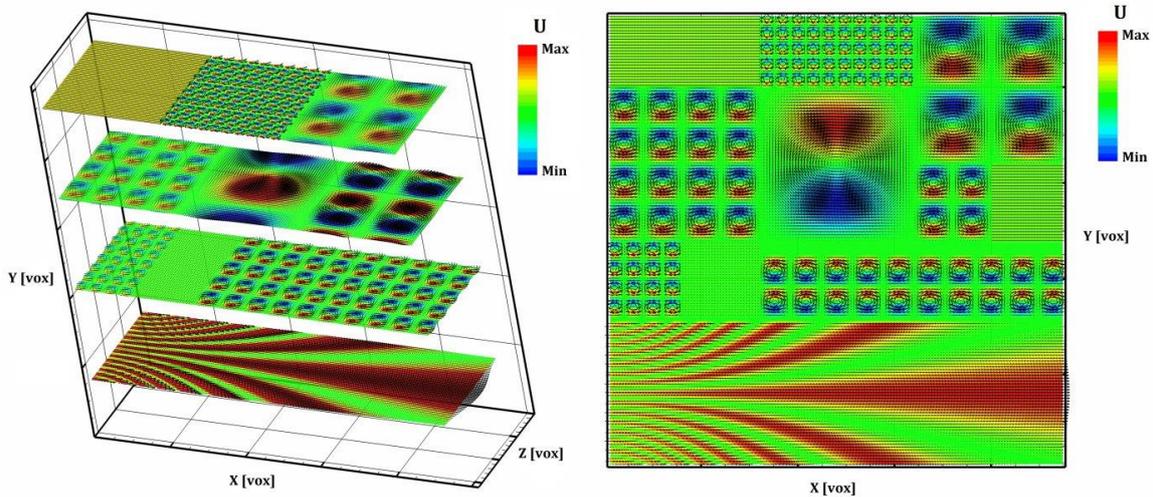
Contour of the *U* component (arbitrary units) of the velocity field and vector representation on XZ planes (left) and on the mid-plane (right).

2.2.1 Calibration images reference table

Name	*z* plane [mm]
C_cal_camZ_0001	-8
C_cal_camZ_0002	-4
C_cal_camZ_0003	0
C_cal_camZ_0004	+4
C_cal_camZ_0005	+8

The separation between the markers on the calibration images is equal to 4*mm* in both the *x* and the *y* direction. The letter Z indicates the camera. The pixel size is $6.5x6.5\mu m$. The images size is 1600x1280 pixels.

2.2.2 Test images reference table

Name	Image density [ppp]
C_camZ_0001	0.01
C_camZ_0002	0.02
C_camZ_0003	0.03
C_camZ_0004	0.04
C_camZ_0005	0.05
C_camZ_0006	0.075
C_camZ_0007	0.10
C_camZ_0008	0.125
C_camZ_0009	0.15

2.3 Desired Quantities

The displacement field (only u, v and w, in *mm*) for the chosen image density (the participant must choose an image density and provide the displacement field only for the chosen density).

The data **must be provided** on the structured grid (included in the file C_Grid.zip, see section 1.3) with a data pitch of 0.2*mm* (4 voxels with a discretization level of 20*vox/mm*). If a resolution different from the suggested one and/or a different grid and/or PTV are used the participant should interpolate their data on the provided structured grid.

The reconstructed volume for images 0006 (relative to an image density equal to 0.075ppp) should be also provided (see section 1.3). This volume should be reconstructed for z varying in the range [-12; 12] *mm*.

The participants must also provide a file "C_YYY_doc.pdf" which outlines the parameters and/or methods which have been used for the complete evaluation (including pre and post processing of data, an example is D_UNINA_doc.pdf).

# 3 Case D

3.1 Introduction

The measurement of the underlying cascade turbulence mechanism at sufficiently high Reynolds number is a challenge for both computational and experimental fluid mechanics in terms of required spatial and dynamic velocity range. The establishment of accurate three-dimensional three-components anemometric techniques is of fundamental importance to both characterize the evolution and organization of the turbulent coherent structures and to provide a benchmark for numerical codes. In the Test case D a 3D PIV experiment is simulated imposing the velocity field of a Direct Numerical Simulation of an isotropic incompressible turbulent flow.

3.2 Technical Information

The test case is performed on time resolved synthetic images of an isotropic turbulent flow field obtained by Direct Numerical Simulation at $Re_\lambda \approx 400$. Projection images of 4 cameras are provided to the participants for a single value of particle concentration. The main challenge of the Test case D is to evaluate correctly the velocity gradient components and, in particular the vorticity in presence of many different length scales within the flow field.
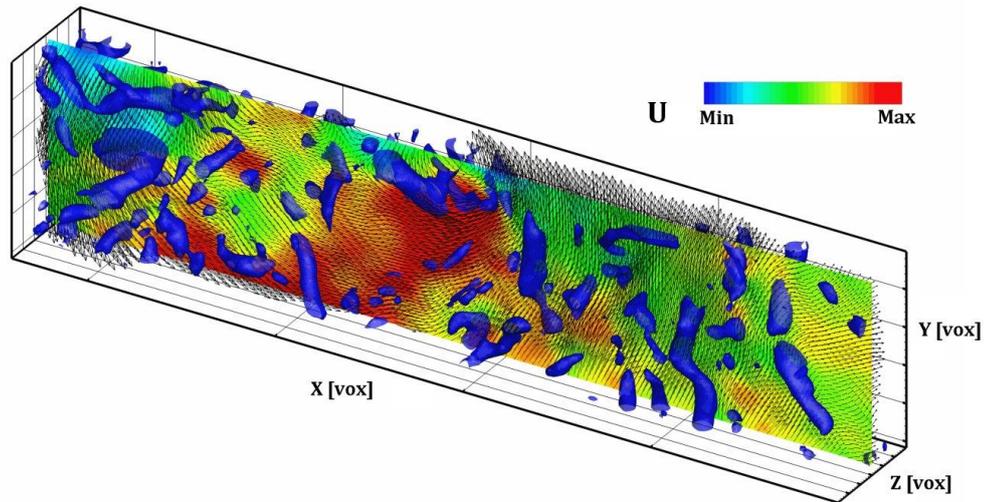
Contour of the U component of the velocity field (arbitrary units) on the XY mid-plane and isosurfaces of the second invariant of the velocity gradient tensor $Q>0$.

The dataset is generated with the following conditions (the volume is centred in the origin):

Volume size: 204.8 x 25.6 x 17.6 mm^3 (4096 x 512 x 352 vox @ 20vox/mm^*)
Particle image diameter: ~ 2.5pixels
Particle image density: ~ 0.1 particles/pixel
Number of volumes: 50

* Suggested resolution but the choice of the resolution value is left open to the contributor.

3.2.1 Calibration images reference table

Name	z plane [mm]
D_cal_camZ_0001	-10
D_cal_camZ_0002	-5
D_cal_camZ_0003	0
D_cal_camZ_0004	+5
D_cal_camZ_0005	+10

The separation between the markers on the calibration images is equal to *5mm* in both the *x* and the *y* direction. The pixel size is $6.5x6.5\mu m$. The images size is 800x4512 pixels.

3.3 Desired Quantities

The results are required only at the following 16 time steps: 2, 5 , 8, …, 44, 47. The participants are free to use two or more images in the correlation and in the tomographic reconstruction but the results are required at the previously mentioned time steps. For example if only two images are used for each time step one would correlate:

"D_camZ_0001.tif" with "D_camZ_0003.tif" and store results in "D_YYY_Var_0002.zip"
"D_camZ_0004.tif" with "D_camZ_0006.tif" and store results in "D_YYY_Var_0005.zip"
$\qquad$: $\qquad$: $\qquad$:
"D_camZ_0043.tif" with "D_camZ_0045.tif" and store results in "D_YYY_Var_0044.zip"
"D_camZ_0046.tif" with "D_camZ_0048.tif" and store results in "D_YYY_Var_0047.zip"

The displacement field, vorticity (u, v and w, in *mm* and vorticity components in *mm/mm*) for all the time steps are requested. The data **must be provided** on the structured grid (included in the file D_Grid.zip, see Sec. 1.4) with a data pitch of 0.4*mm* (8 voxels with a discretization level of 20*vox/mm*). If a resolution different from the suggested one and/or a different grid and/or PTV are used the participant should interpolate their data on the provided structured grid.

The reconstructed volume for the time step 23 should be also provided (see section 1.3). This volume should be reconstructed for *z* varying in the range [-12; 12] *mm*.

The participants must also provide a file "D_YYY_doc.pdf" which outlines the parameters and/or methods which have been used for the complete evaluation (including pre and post processing of data, an example is D_UNINA_doc.pdf).