Technical Report

DNS Database of Roughness-induced Instability & Transition at Mach 6

J. P. J. P. Van den Eynde & N. D. Sandham

Aerodynamics & Flight Mechanics Research Group

Faculty of Engineering and the Environment

University of Southampton

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Contents

This technical report describes the database of Direct Numerical Simulation (DNS) results used in the PhD thesis of Van den Eynde (2015) at the University of Southampton. The raw DNS data has been archived and made publicly available. This makes it possible for the results presented here to be reproduced and allows for further and deeper analysis of the data by the global research community.

This report describes the structure of the database, the nature of the data, and the specifications of the data file formats. It does not include a full explanation of the numerical set-up and details of the different cases, which are given in Van den Eynde (2015).

When using any of this data or publishing results derived from analysis of this database, please use the following citation

> Van den Eynde, J. P. J. P. & Sandham, N. D. (2015), **DNS Database of Roughness-induced Instability & Transition at Mach 6**, `doi:10.5258/SOTON/379712` [available on request]

and the corresponding paper discussing the transition results:

> Van den Eynde, J. P. J. P. & Sandham, N. D. (2015), **Numerical Simulations of Transition due to Isolated Roughness Elements at Mach 6.** *AIAA Journal*, `doi:10.2514/1.J054139`

Or use the following as BibTeX entries:

```
@misc{vandeneynde-2015-database,
 author = {{Van den Eynde}, J. P. J. P. and Sandham, N. D.},
 title  = {DNS Database of Roughness-induced Instability
             \& Transition at Mach 6},
 year   = {2015}
 doi    = {10.5258/SOTON/379712}
}

@article{vandeneynde-2015,
 author  = {{Van den Eynde}, J. P. J. P. and Sandham, N. D.},
 title   = {Numerical Simulations of Transition due to
              Isolated Roughness Elements at Mach 6},
 journal = {AIAA Journal},
 year    = {2015},
 doi     = {10.2514/1.J054139}
}
```

1 Access to the database

Access to the database is open to the public but needs to be requested to the University of Southampton. Please contact the University Library of the University of Southampton, using the following hyperlink, to request the data:
`http://library.soton.ac.uk/datarequest` .

If encountering any problems with the data access, please contact Prof. Neil Sandham (`n.sandham@soton.ac.uk`).

2 Structure of the database

The database contains the raw DNS data sets in two main directories, corresponding to the data used in Chapter 5 and Chapter 7 of Van den Eynde (2015), and Van den Eynde and Sandham (2015). These two main directories are respectively named:

`/Van-den-Eynde_2015_M6_Re8200/`	Data from Chapter 5
`/Van-den-Eynde_2015_M6_Re14000/`	Data from Chapter 7 and Van den Eynde and Sandham (2015)

Each of those directories contain sub-directories for the different roughness element cases. For the results of the receptivity and linear instability growth study in Van den Eynde (2015, Chapter 5), the naming of these sub-directories are given in Table 1. The data used for the roughness-induced transition study in Van den Eynde and Sandham (2015) and Van den Eynde (2015, Chapter 7) can be found in the sub-directories given in Table 2.

Each of these sub-directories contain another two sub-directories,
- 🗀 `./grid/` holding the grid-file,
- 🗀 `./data/` containing the result files from the DNS code `SBLI`.

3 Data file formats

The directories described here contain a variety of different files, i.e. grid files, instantaneous data files, and time-averaged statistics files. It is important to note that each of these files are in a *little-endian binary* format. In this section the binary file format specifications of the different file formats is described, such that the data in these files can be correctly read.

3.1 Grid files

The grid files, included in the 🗀 `./grid/` directories, are named `[casename].xyz` and contain the coordinates of the fully three-dimensional grids $x(i,j,k)$, $y(i,j,k)$, $z(i,j,k)$, with $i = 1, 2, \ldots, N_x$, $j = 1, 2, \ldots, N_y$ and $k = 1, 2, \ldots, N_z$. The full specifications of the file format are given in Table 3.

3.2 Instantaneous flow fields

Instantaneous flow fields in terms of the conservative variables $(\rho, \rho u, \rho v, \rho w, \rho E)^\top$ are written out in (single precision) multi-block `plot3d` files. These files are consistently named `plot3d_q#.####`, in which `#` signifies the block number and `####` signifies the simulation iteration number at which the flow variables are written out.

Table 1. Directories for the roughness cases in Van den Eynde (2015, Chapter 5).

Case	Directory
Bump	🗀 `/Van-den-Eynde_2015_M6_Re8200/Smooth_Bump/`
Cyl (-A)	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Cyl_A/`
Cyl-V	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Cyl_V/`
Cyl-Æ	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Cyl_E/`
Cyl-T0.5	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Cyl_T05/`
Square	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Square/`
Diam	🗀 `/Van-den-Eynde_2015_M6_Re8200/Flat_Diamond/`
R-Up	🗀 `/Van-den-Eynde_2015_M6_Re8200/Ramp_Up/`
R-Down	🗀 `/Van-den-Eynde_2015_M6_Re8200/Ramp_Down/`

Table 2. Directories for the roughness cases in Van den Eynde (2015, Chapter 7) and Van den Eynde and Sandham (2015).

Case	Directory
H-⊗-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Smooth_Bump_Ae5/`
H-⊗-1.0-Ae4	🗀 `/Van-den-Eynde_2015_M6_Re14000/Smooth_Bump_Ae4/`
H-○-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Cyl_Ae5/`
H-○-1.0-Ae4	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Cyl_Ae4/`
H-□-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Square_Ae5/`
H-◇-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Diamond_Ae5/`
H-△-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Ramp_Up_Ae5/`
H-▽-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Ramp_Down_Ae5/`
H-●-0.5-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Cyl_H05/`
H-⬠-1.0-Ae5	🗀 `/Van-den-Eynde_2015_M6_Re14000/Flat_Square_W3/`

The data files for the results in Van den Eynde (2015, Chapter 5), i.e. in directory 🗀 `/Van-den-Eynde_2015_M6_Re8200/`, use single-block flow fields. Multi-block flow fields have been used in Van den Eynde and Sandham (2015) and Van den Eynde (2015, Chapter 7), i.e. the data files in 🗀 `/Van-den-Eynde_2015_M6_Re14000/`. These flow fields in this directory have been divided in a number of blocks in the streamwise direction, such that the complete flow field can be obtained by simply appending the different block files in the streamwise direction.

The file format specification of the individual `plot3d` files is given in Table 4.

3.3 Time-averaged flow field statistics

Time-averaged flow field statistics are written out in `Statistics#.####` files, which have a format similar to the `plot3d` file format but contain 27 statistical quantities instead of the conservative flow variables. The exact specifications of the `Statistics` files are given in Table 5. The statistical quantities contained in these files are given in Table 6.

References

Van den Eynde, J.P.J.P. 'Stability and Transition of the Flow behind Isolated Roughness Elements in Hypersonic Boundary Layers'. Ph.D. thesis, University of Southampton (2015).

Van den Eynde, J.P.J.P. and Sandham, N.D. 'Numerical Simulations of Transition due to Isolated Roughness Elements at Mach 6'. *AIAA Journal* (2015) `doi:10.2514/1.J054139`.

Table 3. Specification of the binary grid file format.

Size (Bytes)	Data Type	Description
8	integer	number of grid points in x-direction nx
8	integer	number of grid points in y-direction ny
8	integer	number of grid points in z-direction nz
8	null	
8	float	x-coordinate $x(1,1,1)$
8	float	x-coordinate $x(2,1,1)$
⋮	⋮	⋮
8	float	x-coordinate $x(\mathtt{nx},1,1)$
8	float	x-coordinate $x(1,2,1)$
⋮	⋮	⋮
8	float	x-coordinate $x(\mathtt{nx},\mathtt{ny},1)$
8	float	x-coordinate $x(1,1,2)$
⋮	⋮	⋮
8	float	x-coordinate $x(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
8	float	y-coordinate $y(1,1,1)$
⋮	⋮	⋮
8	float	y-coordinate $y(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
8	float	z-coordinate $z(1,1,1)$
⋮	⋮	⋮
8	float	z-coordinate $z(\mathtt{nx},\mathtt{ny},\mathtt{nz})$

Table 4. Specification of the binary (single precision) plot3d format containing instantaneous flow fields in conservative flow variables.

Size (Bytes)	Data Type	Description
4	integer	number of grid points in x-direction nx
4	integer	number of grid points in y-direction ny
4	integer	number of grid points in z-direction nz
4	float	Mach number M
4	float	0 (not in use)
4	float	Reynolds number Re
4	float	Time t
4	float	density $\rho(1,1,1)$
4	float	density $\rho(2,1,1)$
⋮	⋮	⋮
4	float	density $\rho(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
4	float	streamwise momentum $\rho u(1,1,1)$
⋮	⋮	⋮
4	float	streamwise momentum $\rho u(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
4	float	wall-normal momentum $\rho v(1,1,1)$
⋮	⋮	⋮
4	float	wall-normal momentum $\rho v(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
4	float	spanwise momentum $\rho w(1,1,1)$
⋮	⋮	⋮
4	float	spanwise momentum $\rho w(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
4	float	total energy $\rho E(1,1,1)$
⋮	⋮	⋮
4	float	total energy $\rho E(\mathtt{nx},\mathtt{ny},\mathtt{nz})$

Table 5. Specification of the binary file format containing time-averaged flow field statistics.

Size (Bytes)	Data Type	Description
4	integer	number of grid points in x-direction nx
4	integer	number of grid points in y-direction ny
4	integer	number of grid points in z-direction nz
4	float	Mach number M
4	float	0 (not in use)
4	float	Reynolds number Re
4	float	Time t
4	float	statistical quantity 1, $q_1(1,1,1)$
4	float	statistical quantity 1, $q_1(2,1,1)$
⋮	⋮	⋮
4	float	statistical quantity 1, $q_1(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
4	float	statistical quantity 2, $q_2(1,1,1)$
⋮	⋮	⋮
4	float	statistical quantity 2, $q_2(\mathtt{nx},\mathtt{ny},\mathtt{nz})$
⋮	⋮	⋮
4	float	statistical quantity 27, $q_{27}(1,1,1)$
⋮	⋮	⋮
4	float	statistical quantity 27, $q_{27}(\mathtt{nx},\mathtt{ny},\mathtt{nz})$

Table 6. Statistical quantities contained in the statistics files.

	1	2	3	4	5	6	7	8	9	10
$\boldsymbol{q}_{\#}$	$\overline{\rho\rho}$	$\overline{\rho u}$	$\overline{\rho v}$	$\overline{\rho w}$	$\overline{\rho\rho\rho}$	$\overline{\rho uu}$	$\overline{\rho uv}$	$\overline{\rho uw}$	$\overline{\rho vv}$	$\overline{\rho vw}$

	11	12	13	14	15	16	17	18	19	20
$\boldsymbol{q}_{\#}$	$\overline{\rho ww}$	$\overline{\rho u}$	$\overline{\rho v}$	$\overline{\rho w}$	$\overline{uu}$	$\overline{uv}$	$\overline{uw}$	$\overline{vv}$	$\overline{vw}$	$\overline{ww}$

	21	22	23	24	25	26	27
$\boldsymbol{q}_{\#}$	$\overline{p}$	$\overline{T}$	$\overline{pp}$	$\overline{TT}$	$\overline{T_0}$	$\overline{T_0T_0}$	$\overline{\rho T}$