FAPESP
AND THE STRATEGIC PROGRAMS TO FOSTER INTERNATIONAL COLLABORATION AND INNOVATION IN THE STATE OF SÃO PAULO

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Engineering Coordination

FAPESP

OUTLINE

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- An Application in Aerodynamics
  - Background Information
  - Proper Orthogonal Decomposition (POD)
  - Dynamic Mode Decomposition (DMD)
- Concluding Remarks

FAPESP - The São Paulo Research Foundation

Brazil: 206 million people, 7th GDP

State of São Paulo, Brazil

42	Million people
32%	of Brazil's GDP
45%	of Brazilian science
13%	of State budget to HE and R&D
1.7% GDP for R&D	

3	State Universities
3+1	Federal H.E. institutions
52	State Tech Faculties
45%	of the PhDs graduated in Brazil (6,131 in 2014)
22	Research Institutes (19 state/3 federal)

FAPESP: São Paulo Research Foundation

- Mission: support research in all fields
- Funded by the State of São Paulo with 1% of all state revenues
- All proposals are peer reviewed (19,769 proposals in 2016)
- Average time for decision: 65 days; 40% success rate
- Annual Expenditures: $PPP 533,9 million in 2016

FAPESP has funding initiatives, mechanisms and strategies that address:

- The Researchers
- The Academic Institutions
- The Research Funding Agencies
- The Industry and Other Economic Sectors

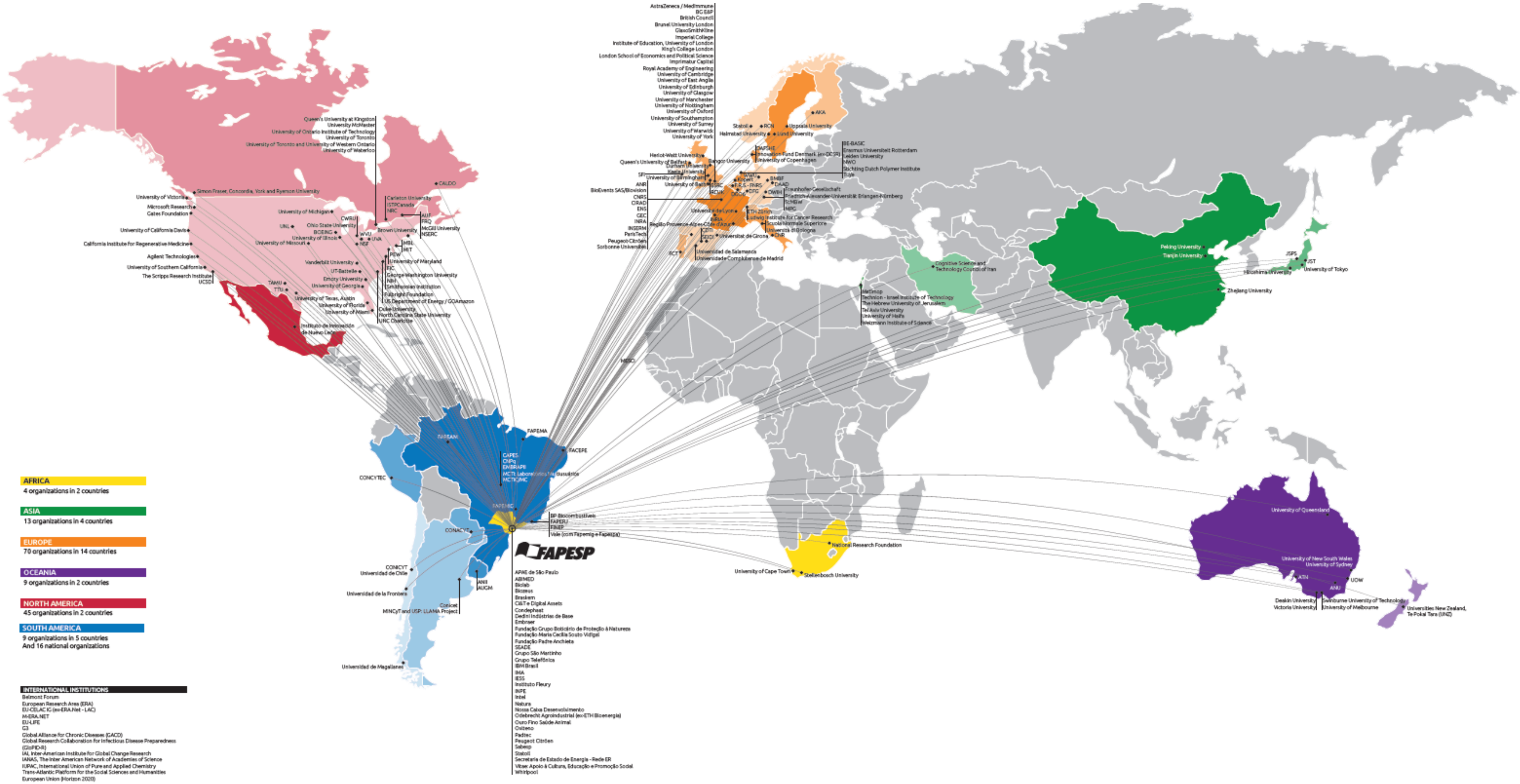
SUPPORT FOR RESEARCHERS

- **Fellowships**
  - In Brazil: 2,000 SI, 1,100 MSc, 3,000 DSc, 2,000 Post-Docs, 800 other
  - Abroad: 1,200 per year
- **Academic R&D**
  - RIDC/11 years, Thematic/5 years, Young Investigators/4 years, Regular/2 years

SUPPORT FOR BUSINESS AND INNOVATION

- **University-Industry Joint R&D** (PITE): Microsoft, Agilent, Braskem, Oxiteno, SABESP, VALE, Natura, Petrobrás, Embraer, Padtec, Biolab, Cristalia, Whirlpool, Boeing, Astra-Zeneca, Intel,
- **Engineering Research Centers**: 10 years joint grants FAPESP/Industry – PCBA, GSK, Natura, BG, Shell
- **Small Business R&D** (PIPE): 228 SBE’s (four awards per week in 2016)

FAPESP Network for International Collaboration



FAPESP - Basic Support Lines

- **SPRINT – São Paulo Researchers in International Collaboration**

  Call for seed funding, initial phases, with the aim to develop a mature collaboration project, agreement required

- **General Agreements (with Funding Agencies)**

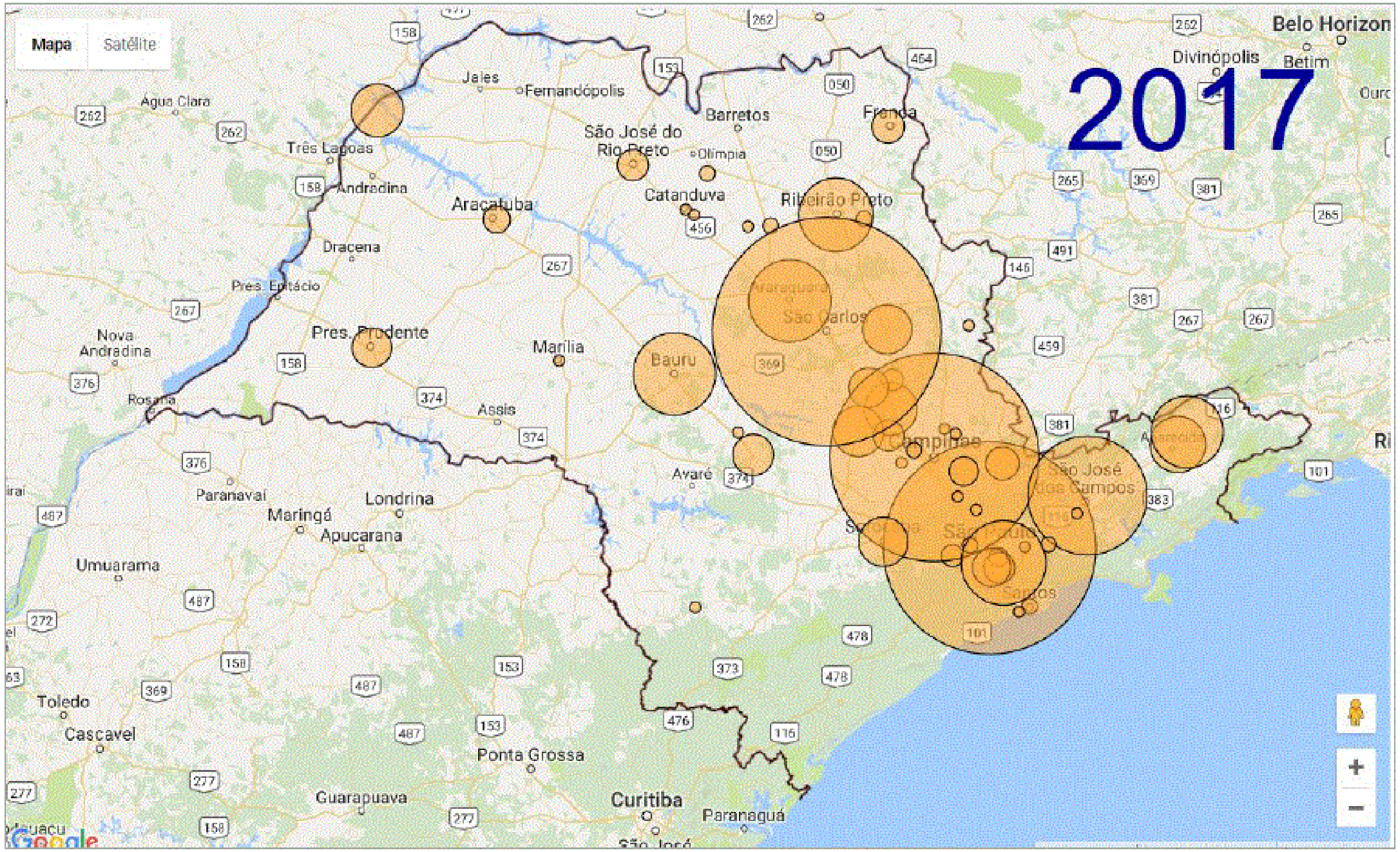
  Larger projects and challenges

- **Remarks:**
  - Agreements: They help but they are not essential.
  - FAPESP has rules, but makes effort to align funding mechanisms.
  - All FAPESP grants may encompass funding for international collaboration.

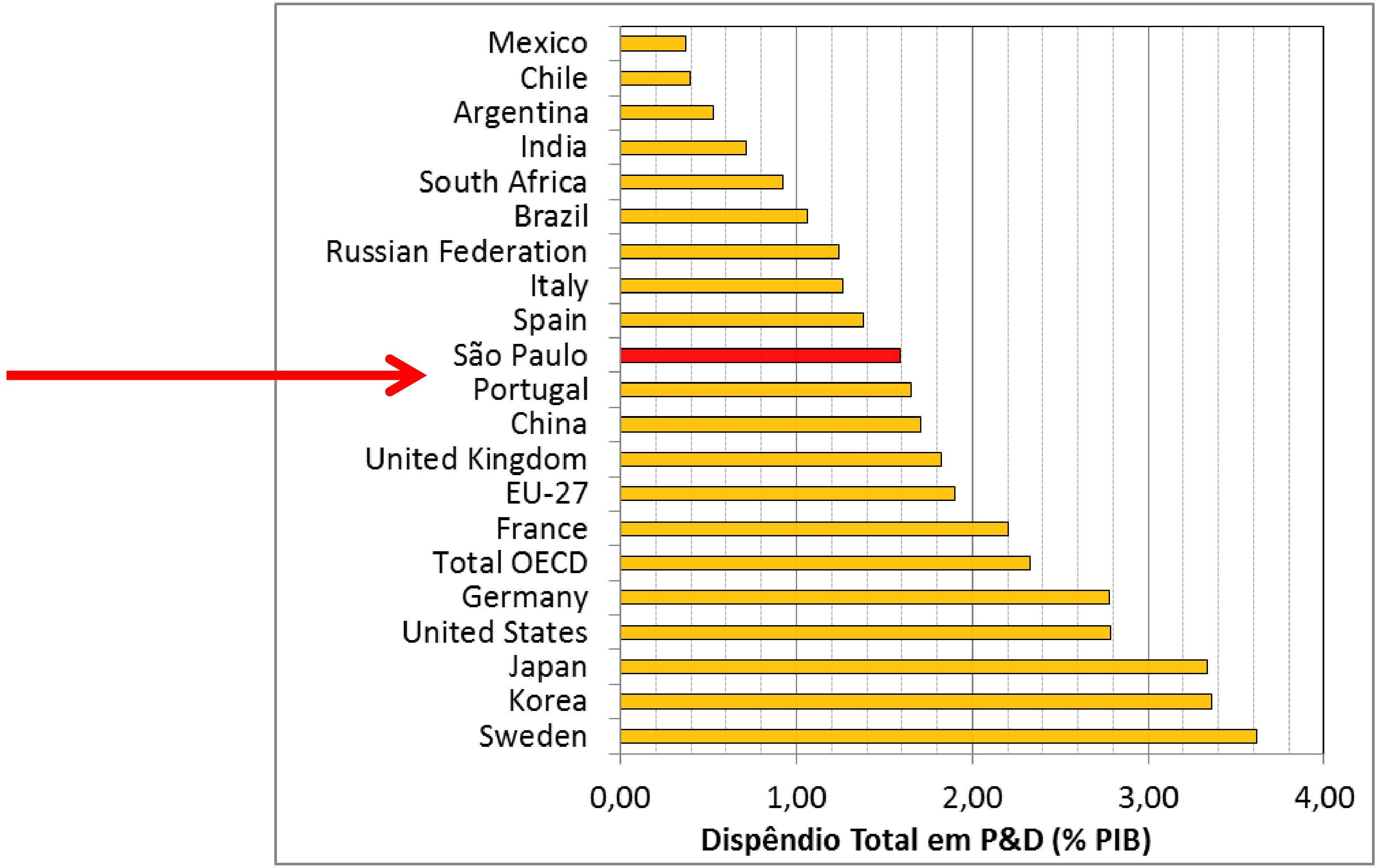
Some Topics Funded by FAPESP and Related to Digitalization

- Nano-structured materials
- Composite materials
- Advanced manufacturing techniques
- Internet of things
- Photonics
- Artificial intelligence
- Bio-fabrication

Spatial Distribution of Funded Digitalization Related Topics in the São Paulo



São Paulo R&D Expenditures International Comparison



An Application in Aerodynamics

Background Information

- We work in Aerospace Engineering
- In particular, our work is mostly concerned with **C**omputational **F**luid **D**ynamics (CFD)
- CFD solves aerodynamic and fluid dynamic problems by returning to fundamental formulations of fluid mechanics and finding numerical solutions for the governing PDE's
- Therefore, at the end, one has values of properties at mesh points (or at cells) for a very large computational mesh
- Particularly for unsteady flows, the amount of information that has to be stored is extremely large
- Hence, in several applications, there is interest in obtaining reduced order models

Motivation

In many scientific areas, such as, fluid dynamics, medicine, finances,. . . , very large datasets are encountered.

- Huge computational meshes - DOF: $\mathcal{O}\ 10^8 \sim 10^{10}$
- Storage: hundreds or thousands of snapshots

Objectives

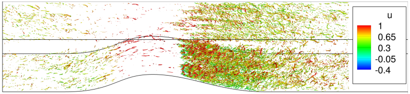
- Identify the dominant behavior of the system dynamics
- Obtain a low-dimensional representation of a high-dimensional problem

Motivation

Extract data from flow...

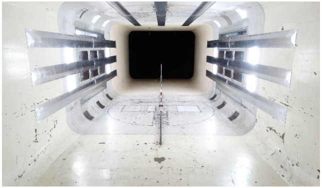
- Simulations

  (velocity, pressure, vorticity fields, etc.)



- Experiments

  (PIV, Schlieren visualizations, LDV, etc.)



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and store it in a matrix

$$M = (v_1^n, v_2^n, \cdots, v_m^n), \tag{1}$$

n is the spatial dimension and m is the number of snapshots ($n \gg m$).

Motivation

Idea:

By processing the matrix of snapshots, M, one can decompose a set of "snapshots" into a sum of spatial modes.

$$\vec{q}\,(\vec{x},t) \;=\; \sum_{n}^{modes} a^{(n)}\,(t)\,\vec{\phi}^{(n)}\,(\vec{x})$$

where $\vec{\phi}^{(n)}\,(\vec{x})$ is the n-th spatial mode, and $a^{(n)}\,(t)$ is its associated temporal coefficient.

Different types of decomposition exist . . .

Proper Orthogonal Decomposition - POD

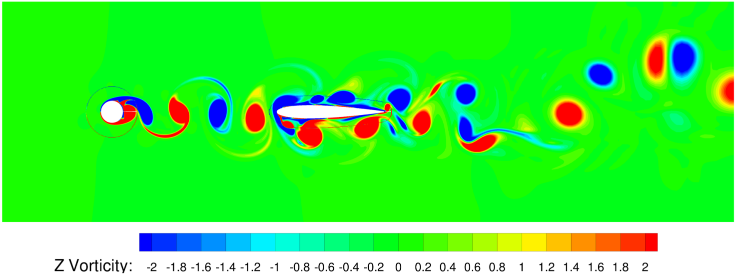
POD is the most traditionally used technique in fluid mechanics (Sirovich, 1987).

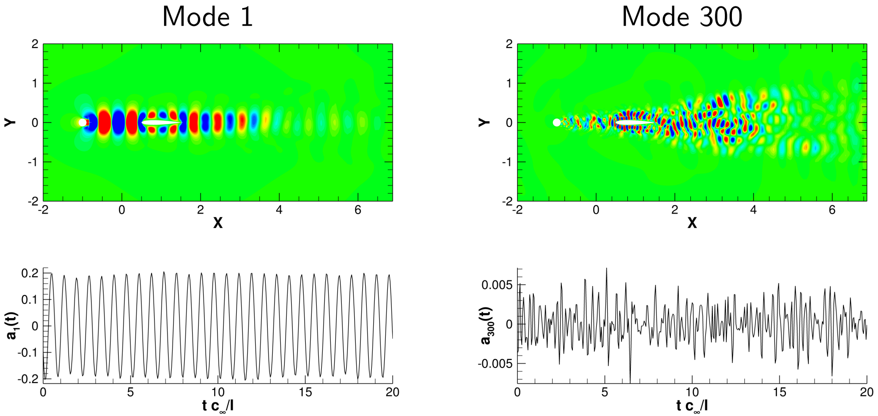
- Modes are organized by their **energy content**
- Space and time are decoupled
- Identify some flow features
  - Coherent structures
  - Noise sources
- Generate low-dimensional systems

POD - Example

Rod-airfoil problem

- Mesh: 850000 points
- Snapshot size: 34Mb
- 4097 snapshots: 136Gb





- Low numbered modes: large scale, low frequency and high energy
- High numbered modes: small scale, high frequency and low energy

POD - Data Compression

Instead of storing 4097 snapshots, we will store some modes!

$$\underbrace{\vec{q}\,(\vec{x},t)}_{\text{snapshot}} = \underbrace{\langle \vec{q}\,(\vec{x})\rangle}_{\text{mean}} + \sum_{n}^{modes} \underbrace{a^{(n)}\,(t)}_{\text{amplitude}}\, \underbrace{\vec{\phi}^{(n)}\,(\vec{x})}_{\text{mode}}$$

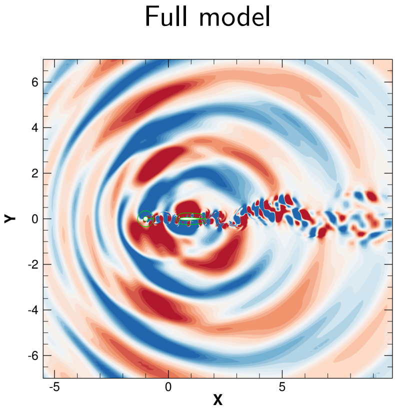
The cost of storing information corresponding to one snapshot is the same of storing one mode.

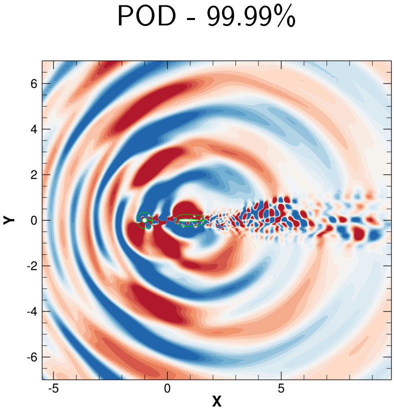
POD - Data Compression

Full model size (Gb)	Number of modes	Energy	New model size (Gb)	Reduction
136	67	90.00 %	2.2	-98.4%
136	230	99.00 %	7.6	-94.4%
136	428	99.90 %	14.2	-89.6%
136	715	99.99 %	23.7	-82.5%

Keeping 99.99% of the flow energy, we can reduce storage costs by 82.5% (from 136Gb to 23.7Gb)

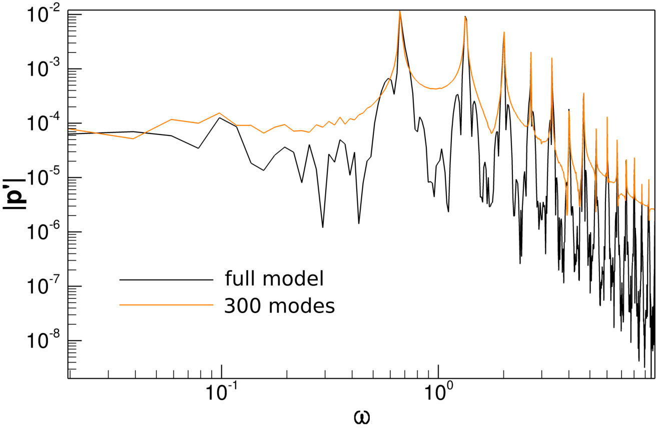
Proper Orthogonal Decomposition - POD





POD - Extracting Noise Sources

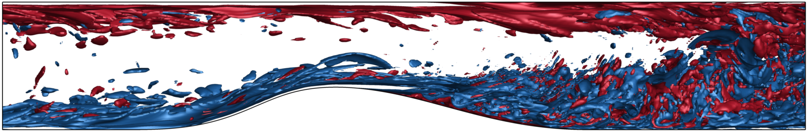
Recover all the tonal noise peaks



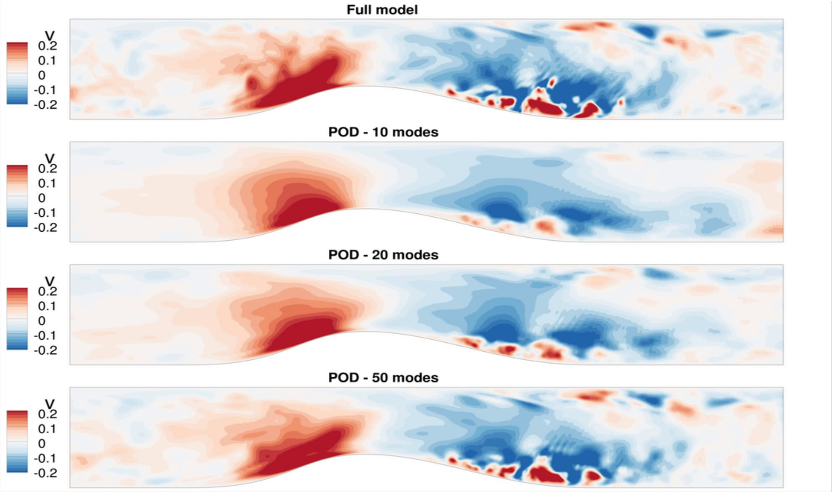
POD - Application in Turbulent Flows

3D convergent-divergent channel

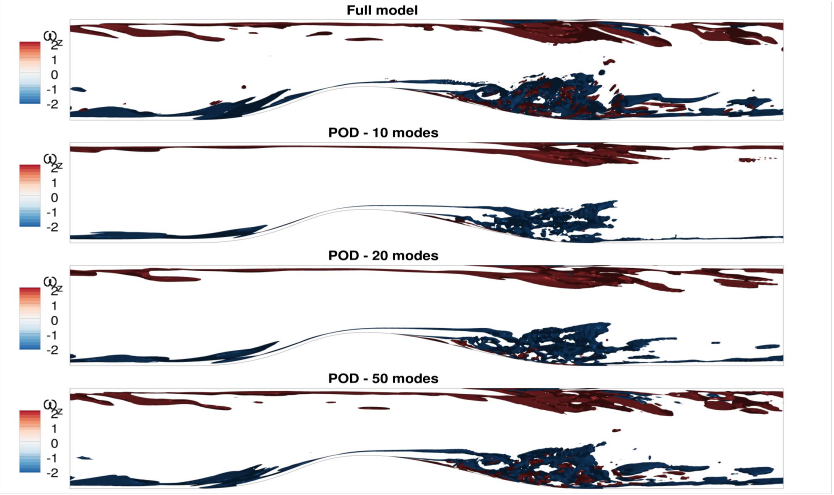
- Mesh: 12 million points
- Snapshot size: 355Mb
- 513 snapshots: 177.8Gb



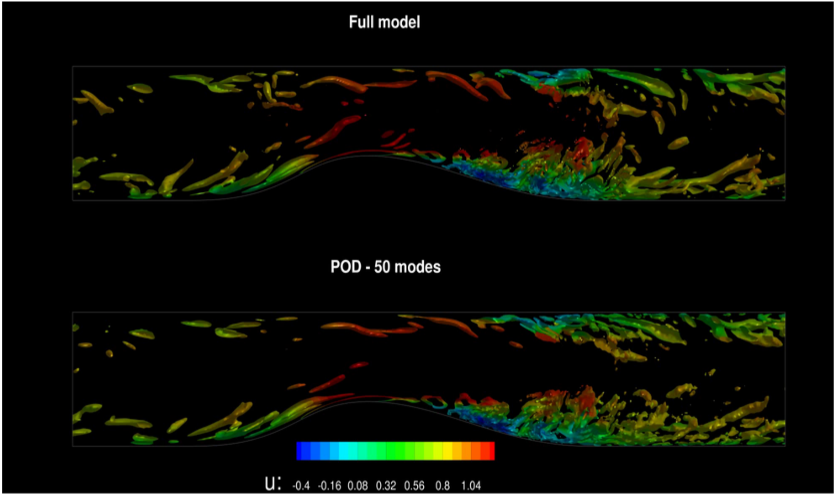
Reconstruction of V velocity component



Z vorticity reconstruction



Q criterion



Dynamic Mode Decomposition - DMD

Technique based on the Koopman operator, a linear operator that can be defined for any nonlinear system (Schmid, 2010).

- Modes organized by their **single frequency content**;
- Matrix-free method;
- Identify some flow features;
- Better understand flow dynamics;
- Generate low-dimensional systems.

Various strategies. . .

- Sparsity-promoting DMD
- Streaming DMD
- Extended DMD, . . .

. . . for various applications

- Fluid Mechanics
- Medicine, Epidemiology, Neuroscience
- Power Systems, Robotics, Video Processing
- Sustainable Buildings, . . .

Streaming DMD - Preliminary Results

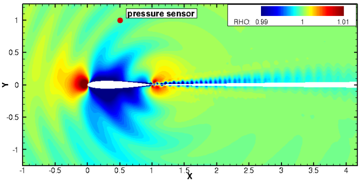
Chosen strategy : Streaming DMD (Hemati *et al.*, 2014).

Case of study: Thin trailing-edge NACA0012 airfoil

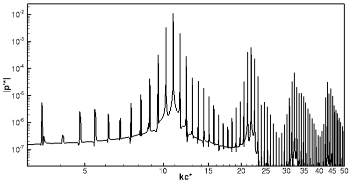
$$(AoA = 0,\ M = 0.3, Re = 10^5)$$

- Mesh: 360000 points
- Snapshot size: 14Mb
- 1000 snapshots: 14Gb
- 25 modes conserved

Snapshot of the density



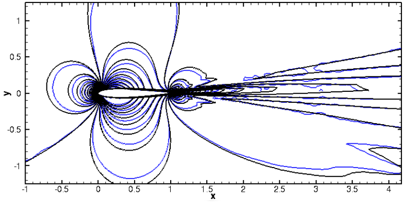
Near-field pressure spectrum



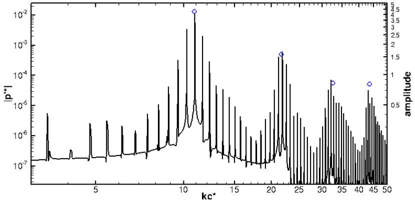
Streaming DMD - Preliminary Results

Comparison between simulation results and DMD

Mean flow comparison



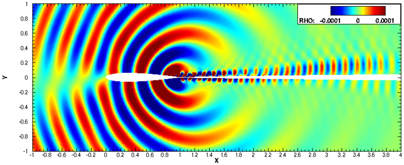
Near-field pressure spectrum comparison



Streaming DMD - Preliminary Results

DMD mode corresponding to the each frequency

Real part of the density



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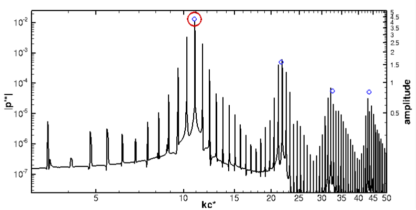

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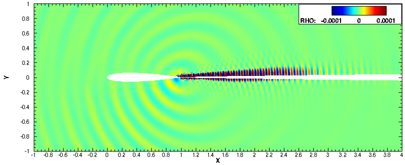

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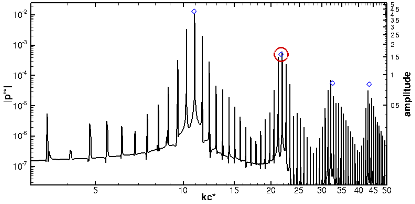

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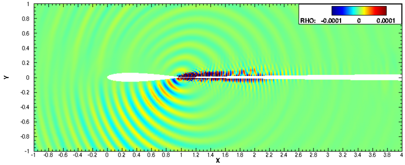

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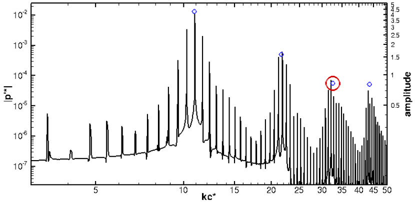

Streaming DMD - Preliminary Results

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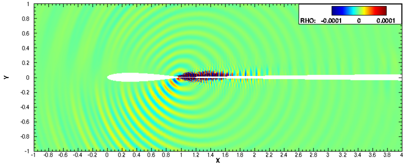
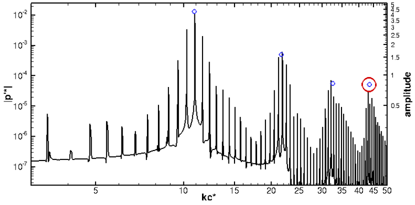


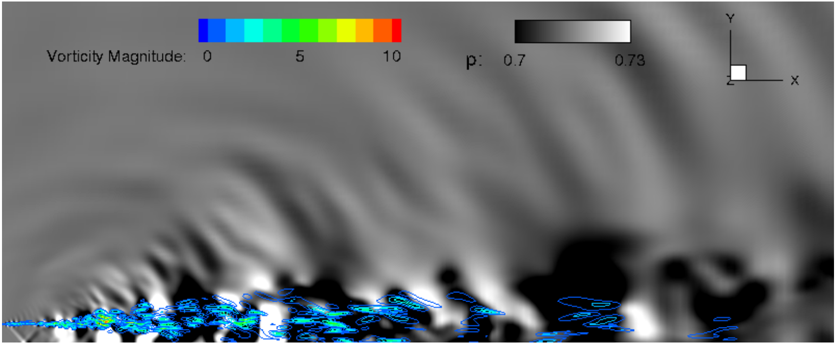
Near-field pressure spectrum comparison



Towards Other Applications

Other cases are being studied to be compared with POD results:

- Rod-airfoil problem
- Channel flow
- Supersonic jet flow



Concluding Remarks

Concluding Remarks

- The long term goals of this work are:
  - to contribute to the understanding (and modeling) of turbulent flows
  - to reduce the costs in the treatment of aeroacoustic problems
- All the work described here has been performed under a FAPESP RIDC project (center): CeMEAI (Center for Industrial Mathematics Applications)
- The availability of the computational resources at the CeMEAI RIDC is absolutely essential for our work