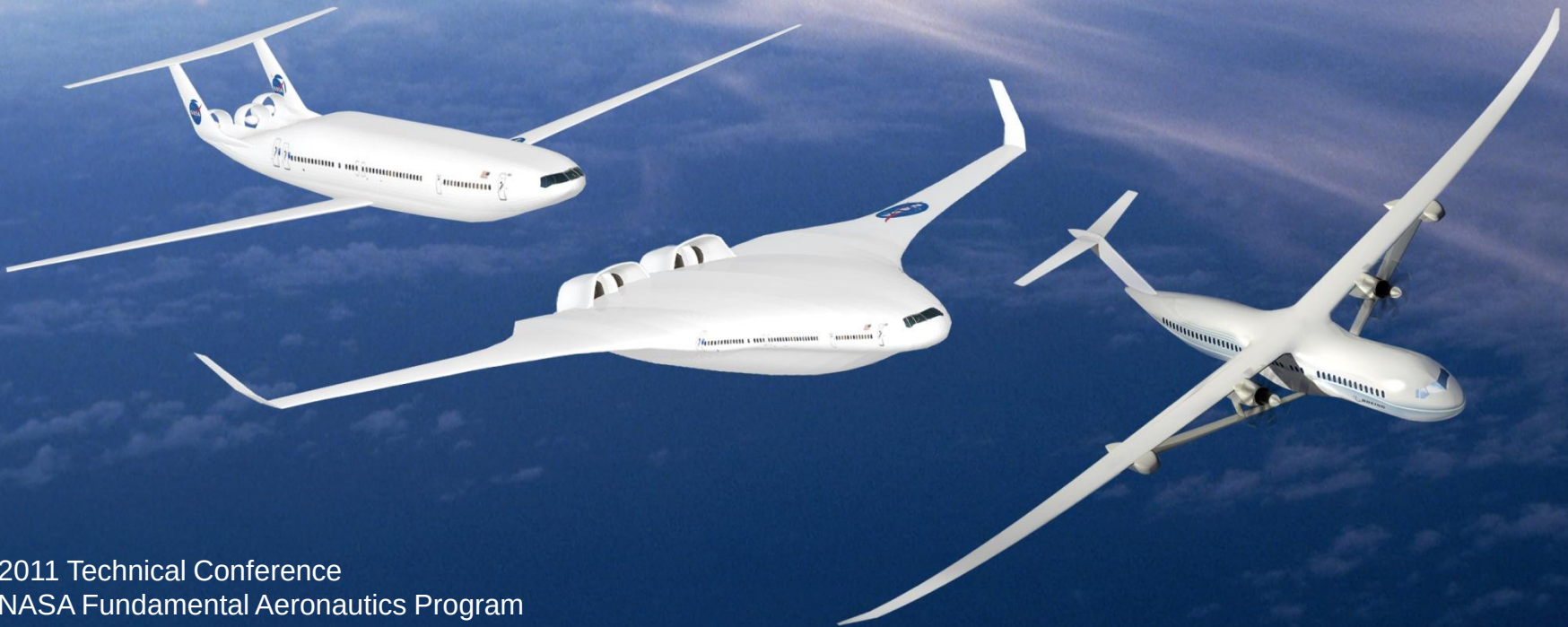




Overview of the Workshop on Benchmark Problems for Airframe Noise Computations (BANC-I) and Prospects for BANC-II

Dr. David P. Lockard and Dr. Meelan M. Choudhari

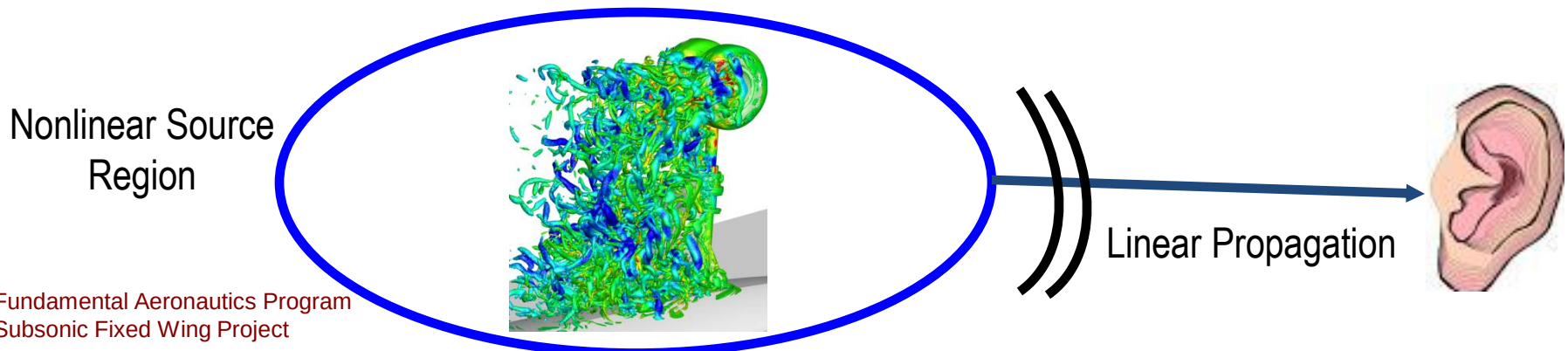
**Aerospace Engineers
NASA Langley Research Center**



2011 Technical Conference
NASA Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Cleveland, OH, March 15 - 17, 2011

Background

- Computational Aeroacoustics has outgrown the range of simple unit problems
- Airframe noise problems require inherent complexity of underlying unsteady fluid dynamics to be addressed
- Paradigm evolution:
 - Closed form/“exact” solutions
 - Single-facility/single-organization experiments
 - Multiple investigator/multi-facility experiments to address the **full chain of causality from near-field unsteadiness to far-field acoustics**





BANC-I and BANC-II Workshops

Organized by AIAA Aeroacoustics/Fluid Dynamics Technical Committee's Discussion Group on Benchmark Experiments and Computations for Airframe Noise (BE & CAN)

Meelan Choudhari, NASA Langley Research Center
& **Miguel Visbal**, Air Force Research Laboratories

➤ <https://info.aiaa.org/tac/ASG/FDTC/DG/BECAN.aspx>

Purpose:

To define a hierarchical set of benchmark configurations for collective investigations of airframe noise sources and to **facilitate joint development of appropriate datasets and coordinated computational and modeling efforts.**

Community activity: Everyone is welcome to participate

➤ **Meelan.M.Choudhari@nasa.gov**



Problem Selection for BANC-I

- **Jan 2008: Identification of suitable problem categories**
- **May 2008: Confirmation of 4 problem categories for BANC-I based on broad current interest + availability of dataset(s)**
- **May 2008: Team leads drafted for each problem category, with instructions to seek additional help as necessary**
 - Teams worked more or less independently to prepare preliminary problem statements
- **May 2009, Special session at Aeroacoustics Conference**
 - Provided outline of datasets, including clarification of measurement process/limitations + interplay with computations
 - Problem statements/revisions posted to the DG website
- **Announcements distributed at summer and winter AIAA meetings, link via 2010 Aeroacoustics Conference, email, flyers at other specialist's meetings**

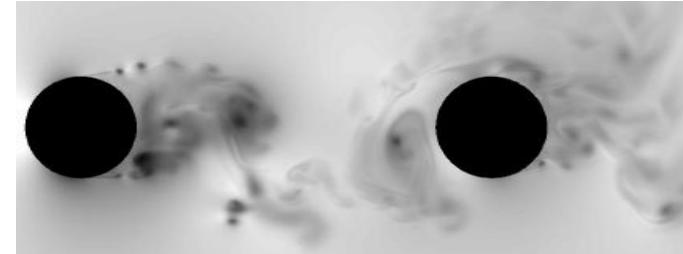
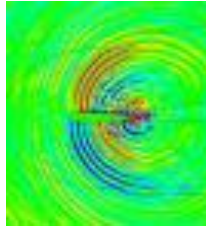
- June 10-11, 2010, after AIAA Aeroacoustics Conference
- Strong participation: 85+ attendees
 - 14 countries, 8 government organizations/research consortia, 5 large industry organizations, 4 software vendors, academia
- BANC-I Objectives
 - Provide a forum for a thorough **assessment of simulation-based noise-prediction tools** in the context of airframe configurations including both near-field unsteady flow and the acoustic radiation generated via the interaction of this flow with solid surfaces.
 - **Identify current gaps in physical understanding, experimental databases, and prediction capability** for the major sources of airframe noise.
 - **Help determine best practices, and accelerate the development of benchmark quality datasets.**
 - **Promote future coordinated studies** of common configurations for maximum impact on the current state of the art in the understanding and prediction of airframe noise.

BANC-I Problem Categories



1. Airfoil Trailing Edge Noise

- Canonical problem, final frontier for AFN

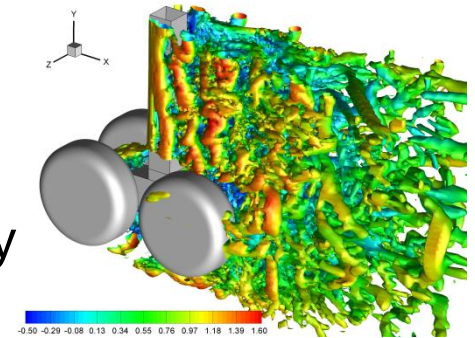


2. Unsteady Wake Interference Between a Pair of Tandem Cylinders

- Developed as a model, comprehensive aeroacoustic dataset
- Deceptively simple: requires substantial compute power, grid convergence not demonstrated

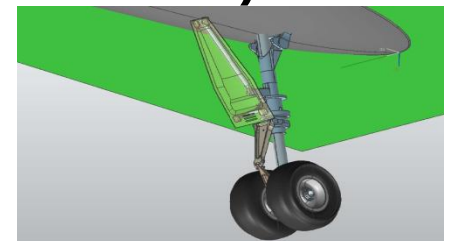
3. Rudimentary Landing Gear (RLG)

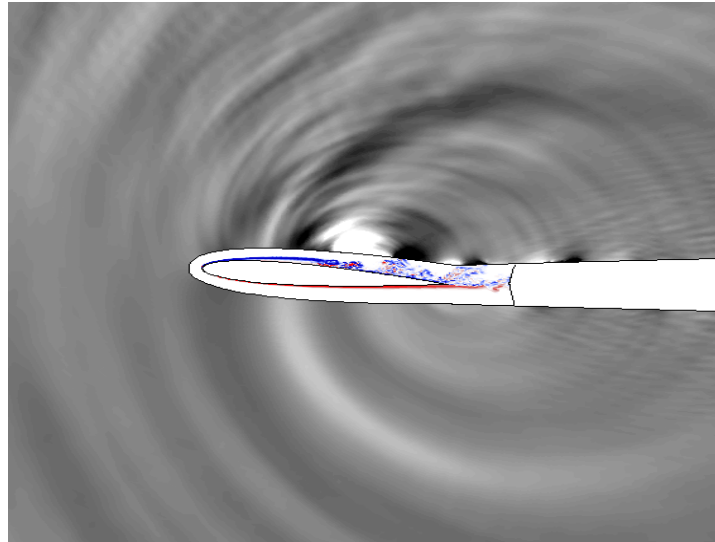
- Square posts to minimize Reynolds number effects
- Evolving nature of experiment allows greater interplay between simulations and experiment design



4. Partially Dressed Cavity Closed Landing Gear (PDCC-NLG)

- Reflects complexity of real landing gear





Category 1

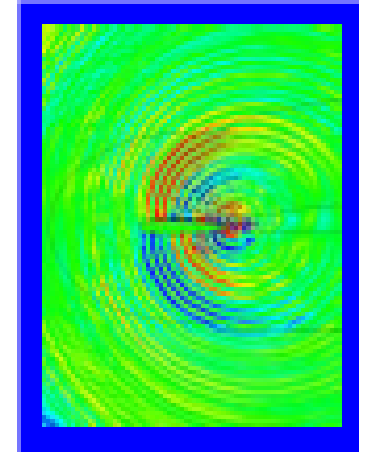
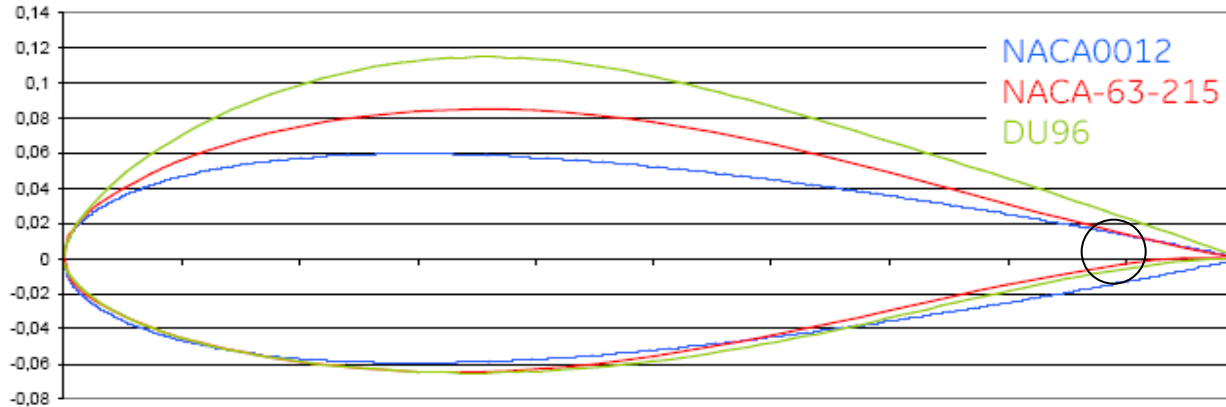
Airfoil TE Noise

Airfoil Trailing Edge Noise



Courtesy: Kinzie, Drobietz (GE)

Other team members: Brentner, Glegg, Devenport, Delfs



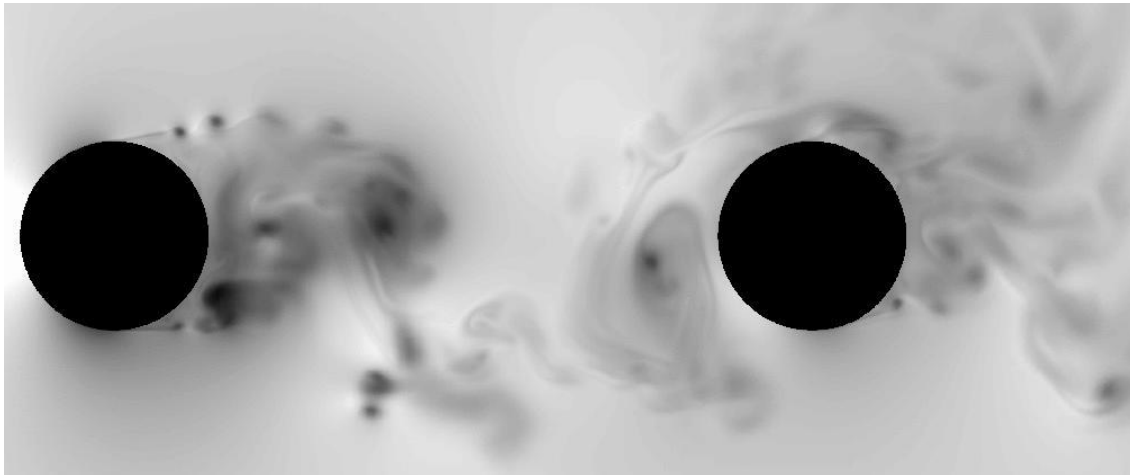
- **Simulate a NACA 0012 airfoil in free air**
 - a) Chord = 22 cm, $U = 40$ m/s and 70 m/s
 - c) $\alpha = 0^\circ$ and 7°
 - d) $Tu = 0.05\%$ at the airfoil leading edge
- **Compare specified mean flow, unsteadiness and acoustic metrics with one additional applied airfoil configuration from**
 - a) **DU-96-180** with 50 cm chord
 - b) **NACA-63-215** with 50 cm chord
- Illustrate the relationship of flow characteristics to noise generation

Observations on Airfoil Trailing Edge Noise



- **Somewhat loose and open-ended problem statement sought a comparative assessment of multiple flow configurations (geometry + flow conditions)**
 - Participants requested more structure in problem statement, presentation format in the future
- **No benchmark measurements were used as anchor, mainly code-to-code comparisons and physical insights were sought**
- **Weak response, with disparate interpretation of “simulations”**
 - Lattice Boltzmann simulation
 - RANS + CAA
 - TBL + Modeling
 - Low-Re DNS
- **Need for improved problem statement in terms of**
 - Trip definition
 - Clearer definition of a single core case, with data from multiple experiments

*Many similarities in predicted spectra,
but also major differences
No statistical inferences feasible*

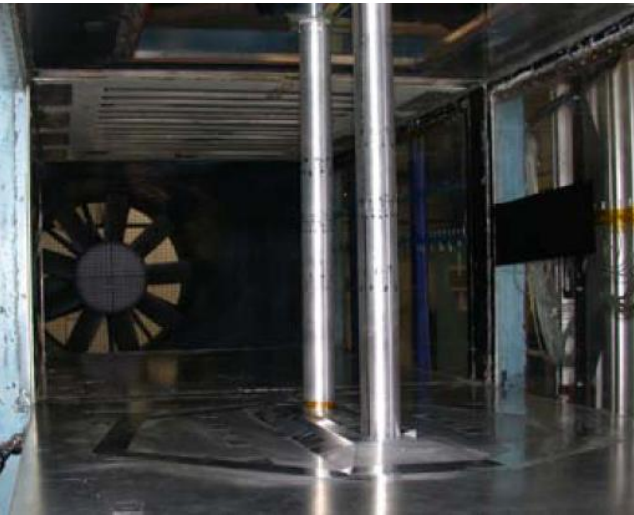


Review Paper: AIAA-2011-353

Category 2

Tandem Cylinders

Tandem Cylinder Experiments for Simulation Development / Validation

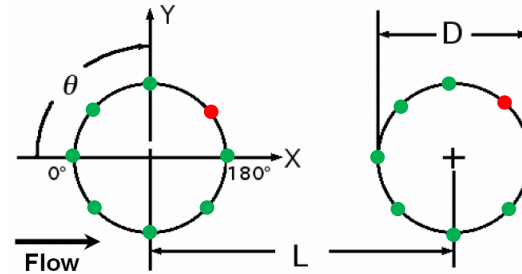
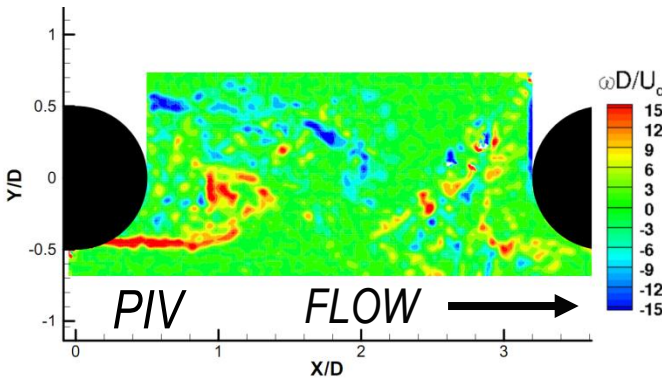


Basic Aerodynamic
Research Tunnel

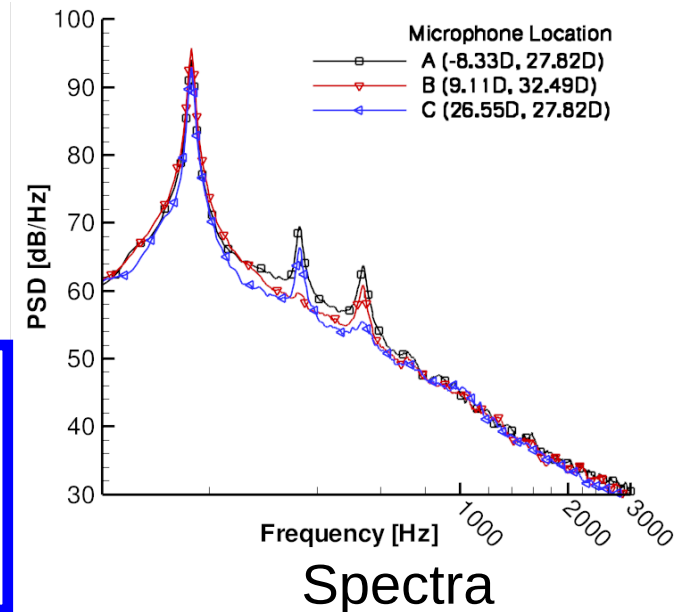
- Steady surface pressure
- Unsteady surface pressure
 - Circumferential ring
 - Spanwise row
- PIV – velocities and Reynolds stresses
- Mic measurements
 - Out-of-flow fixed and traversing



Quiet Flow Facility



Extensive experimental
dataset available for
testing CFD/LES
methods



Participants



ID	Organization	Contributors
1	CD Adapco	O. Aybay
2	EXA	G. Bres
3	ONERA	F. Houssen, F. Vuillot, E. Manoha and S. Redonnet
4	JAXA	T. Imamura, T. Hirai, S. Enomoto and K. Yamamoto
5a	NASA	D. Lockard
5b	NASA	D. Lockard
6	NASA	D. Lockard and P. Buning
7	UCL	Y. Marichal, L. Bricteux, M. Duponcheel, G. Winckelmans, C. Carton de Wiart and P. Geuzaine
8a	NTS	A. Garbaruk, M. Shur, M. Strelets, P. R. Spalart and R. Balakrishnan
8b	NTS	A. Garbaruk, M. Shur, M. Strelets, P. R. Spalart and R. Balakrishnan
9	ONERA	M. Terracol
10	FSU	A. Uzun and M. Y. Hussaini
11	NASA	V. Vatsa
12	Southampton	M. Weinmann, R. D. Sandberg and C. J. Doolan
13	TUB	B. Greschner, C. Mockett and F. Thiele
14	DLR	K. Weinman
15	Stanford	C. C. Yu, W. R. Wolf, R. Bhaskaran and S. K. Lele

15 groups participated

– Many submitted multiple solutions

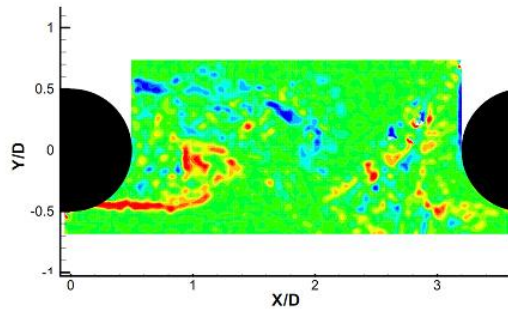
Computational Details



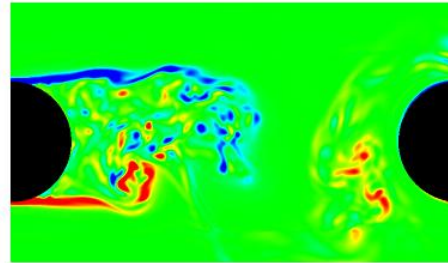
ID	Code	Turbulence Model	Time Step Algorithm	Span/D	Grid Points (millions)	Time Steps	Subiterations Per Time Step
1	STAR-CCM+	SST DES		12	6.7	100000	5
2	PowerFLOW	k- ϵ DES	Explicit	16	66	1360874	1
3	CEDRE	SST DDES	Implicit RK12	4	17	1000000	20
4	UPACS-LES	Zonal S-A	MFGS	18	70	297463	5
5a	CFL3D	S-A MDDES	Dual-time	3	10	59000	20
5b	CFL3D	Zonal SST	Dual-time	18	60	59000	20
6	OVERFLOW	S-A MDDES	Dual-time	3	16	233973	20
7	ARGO	S-A DDES	Dual-Time	4	10	100000	
8a	NTS Code	S-A DDES	Dual-time	3	11	38461	15
8b	NTS Code	S-A DDES	Dual-time	16	60	153846	30
9	FUNK	LES	Implicit Gear	4	16	500000	5
10	FSU Code	S-A DDES	Implicit B-W	6	133	512820	3
11	FUN3D	HRLES	Dual-time	3	8.7	59200	15
12	OpenFOAM	FSM SST	pisoFOAM	3	2	325287	
13	ELAN	S-A DDES	Implicit	3	10	40000	10
14	TAU	S-A DDES	Dual-time	3	11	14000	150

Most used hybrid RANS/LES

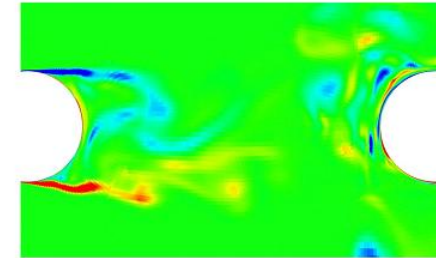
Instantaneous Spanwise Vorticity



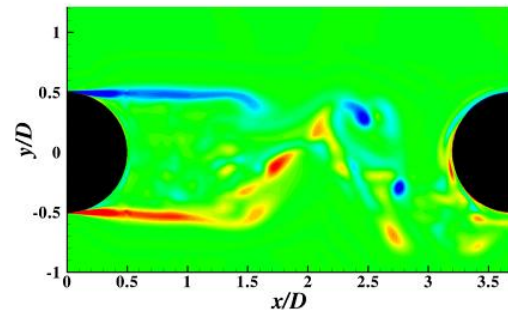
(a) BART PIV



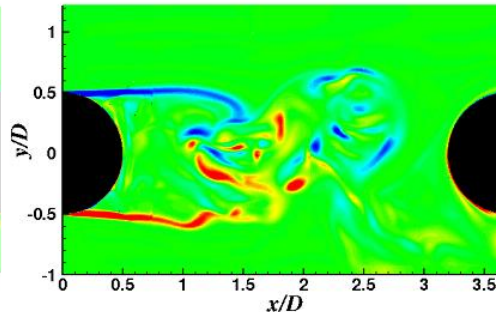
(b) 2-PowerFLOW



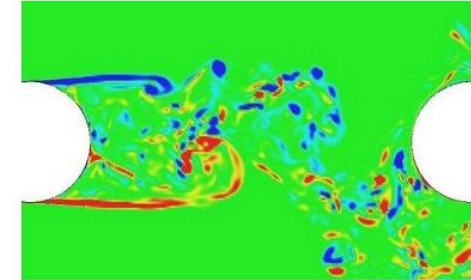
(c) 3-CEDRE



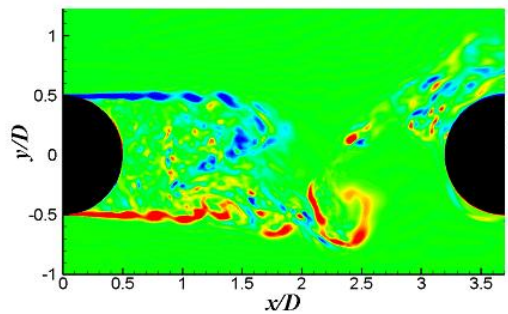
(d) 4-UPACS-LES



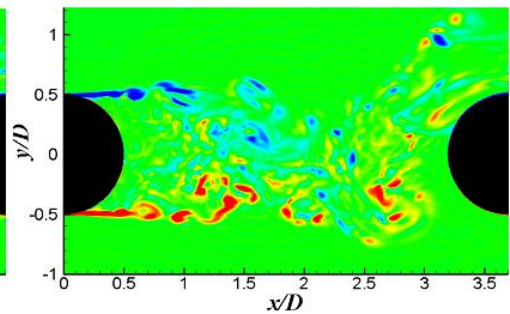
(e) 5b-CFL3D



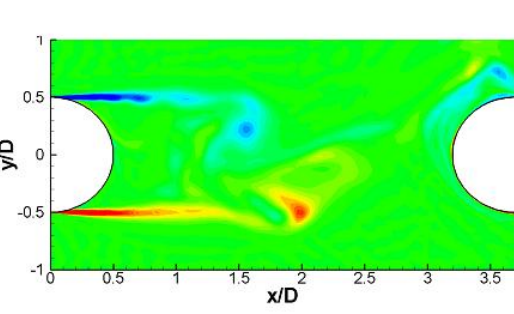
(f) 6-OVERFLOW



(g) 8a-NTS



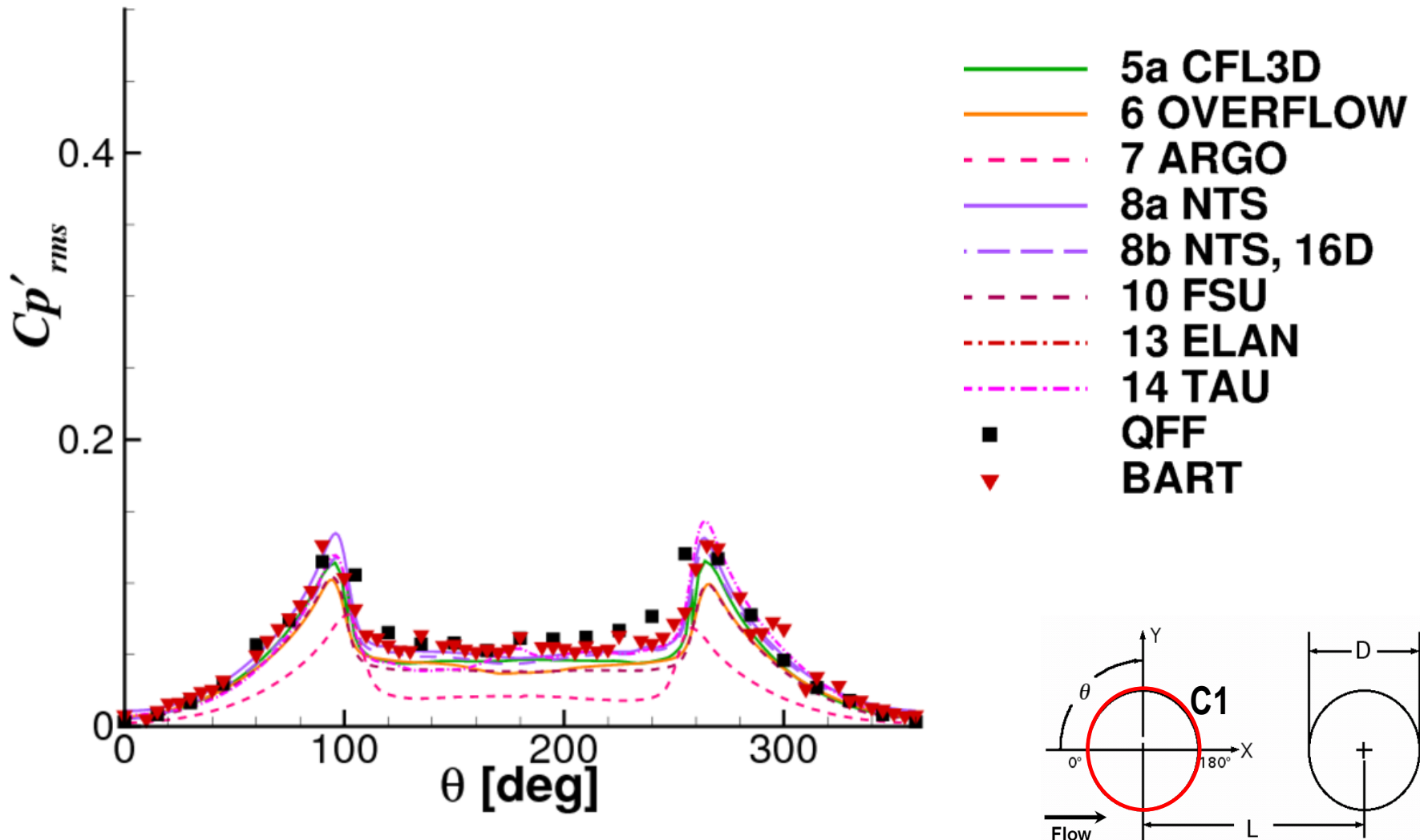
(h) 8b-NTS



(i) 12-OpenFOAM

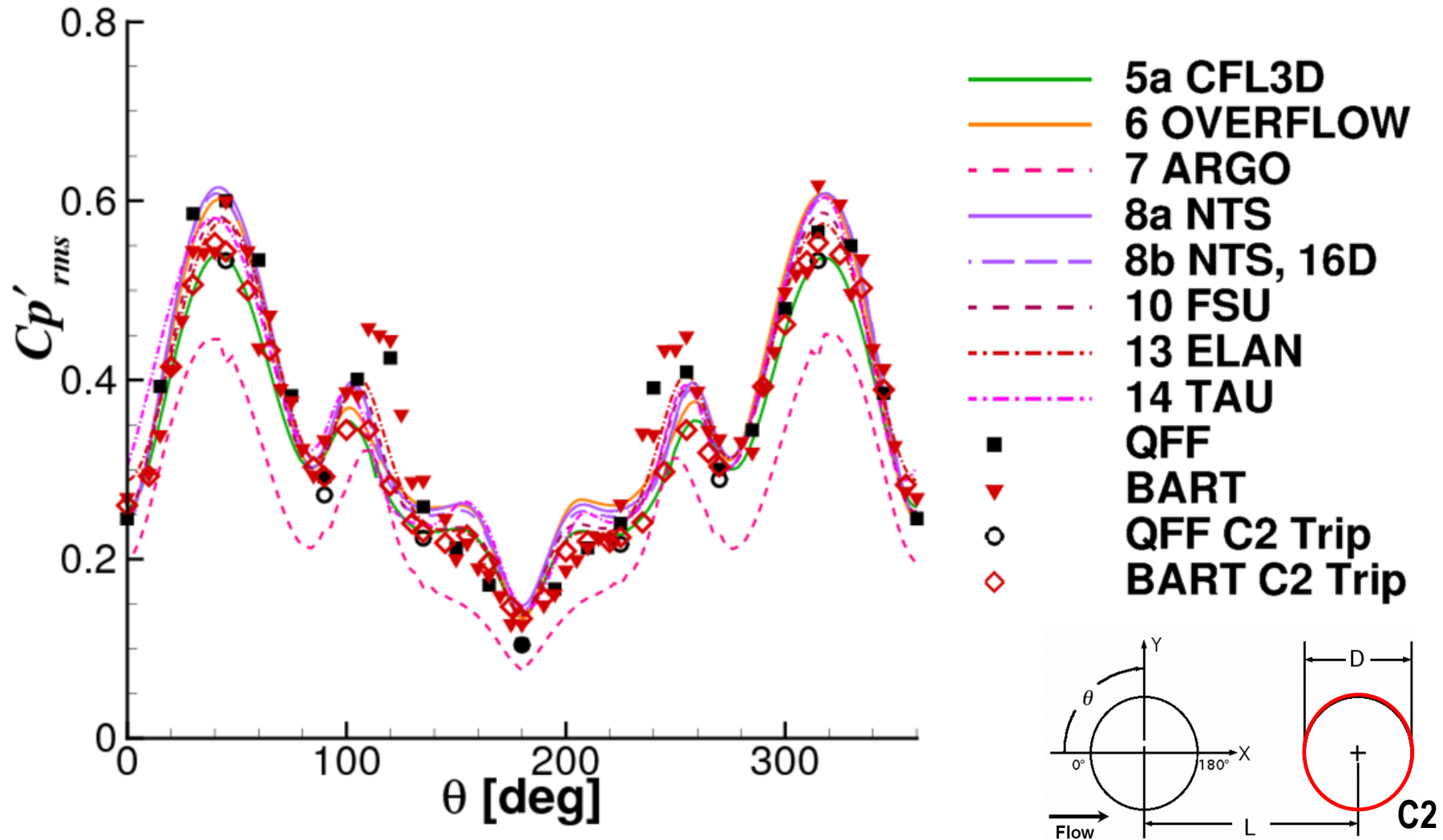


Upstream Cp'_{rms} : DDES



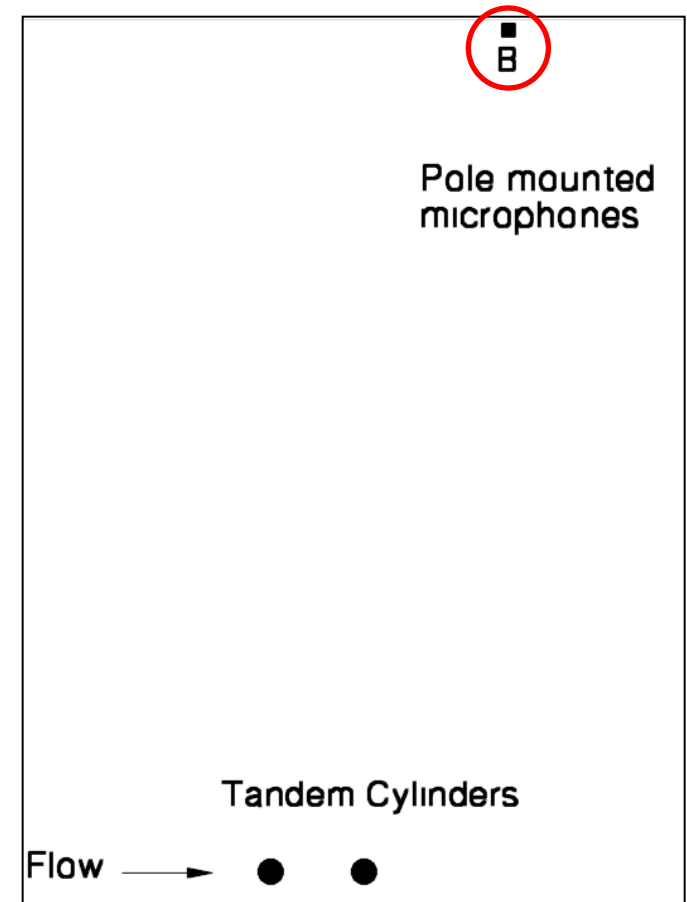
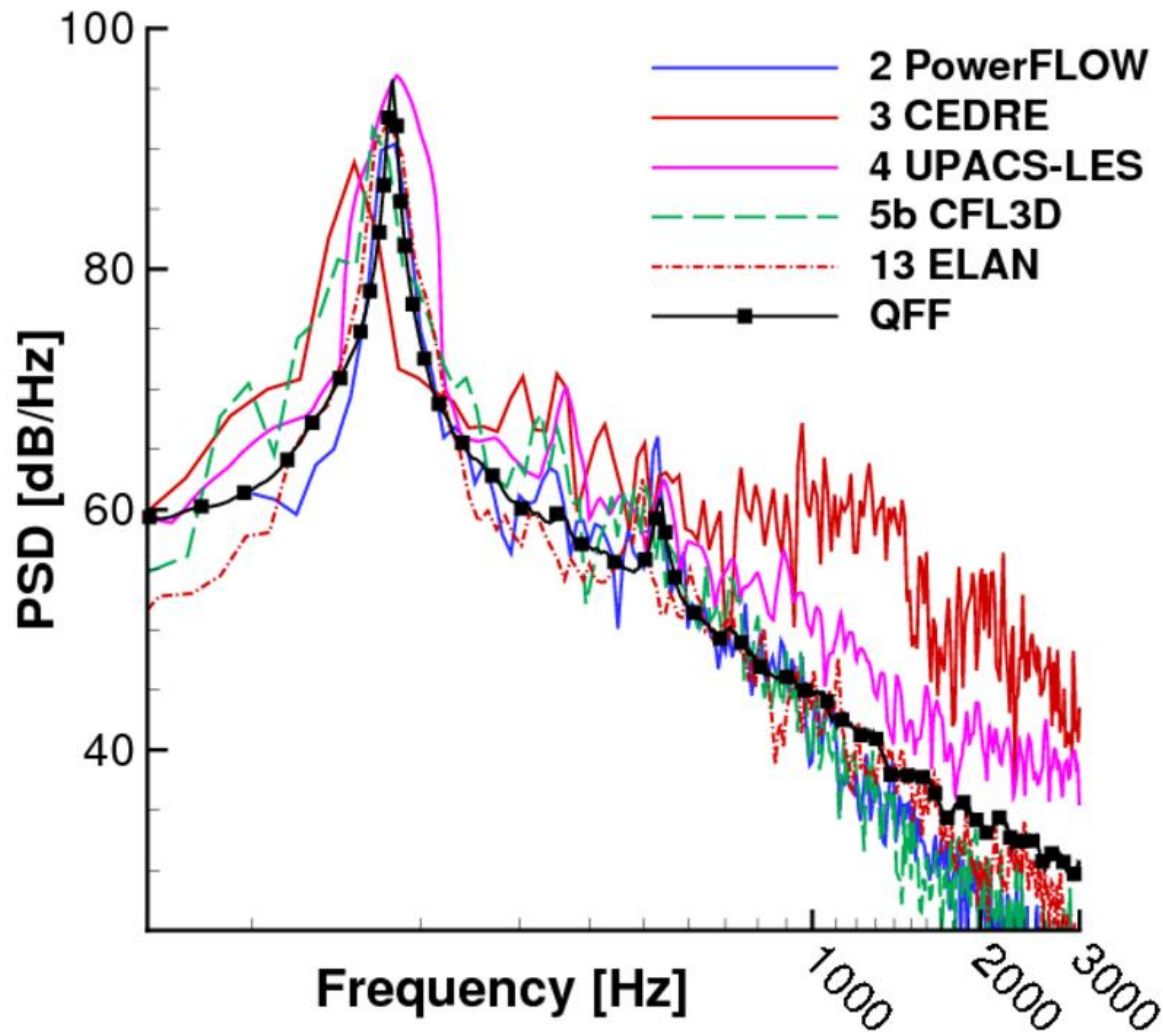
Good agreement between most of the DDES simulations

Downstream Cp'_{rms} : DDES



Secondary peak significantly decreased by trip on C2

Acoustic Spectra



How close can we expect to get?

Tandem Cylinder Summary I

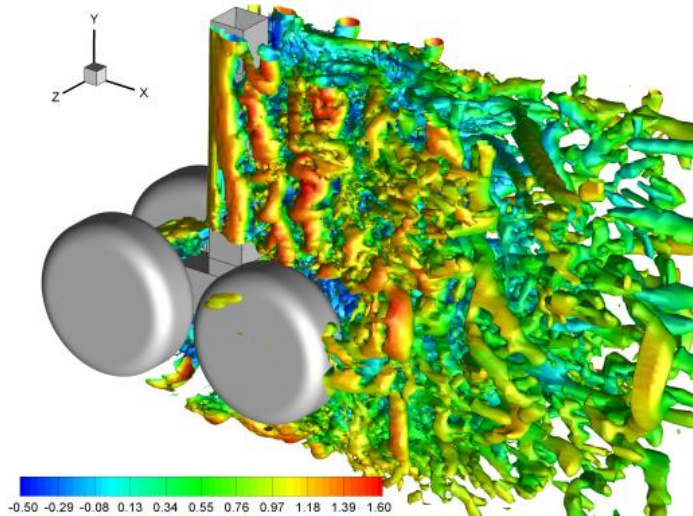


- 15 groups completed simulations
 - Most used hybrid RANS/LES
- Nearly all solutions exhibited qualitatively similar behavior to experiments
- Pure LES had more difficulties simulating the transition strip/high Re aspects of the flow
- DDES solutions similar to each other for many quantities

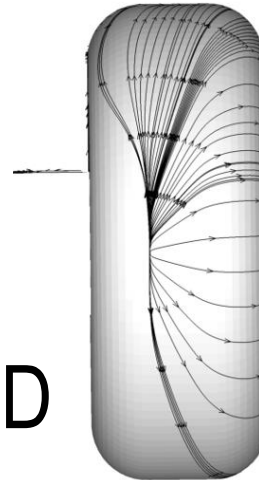
Tandem Cylinder Summary II



- No simulation was able to get all the details correct
 - Very large standard deviation in some quantities
 - And this wasn't a blind test – but tuning impractical because of cost of simulations
 - Influence of grid, time step, turbulence model ... needs to be systematically explored
- Some aspects may be unrealistically difficult
 - 3D simulation of a 2D extruded body
 - Turbulent separation on a highly curved surface
 - Difficult to model a transition strip
- 13 million CPU-hours expended on 14 solutions to a “simple” case
 - Implications for complex problems
 - Suggests we need further workshops



CFD



Expt

Category 3

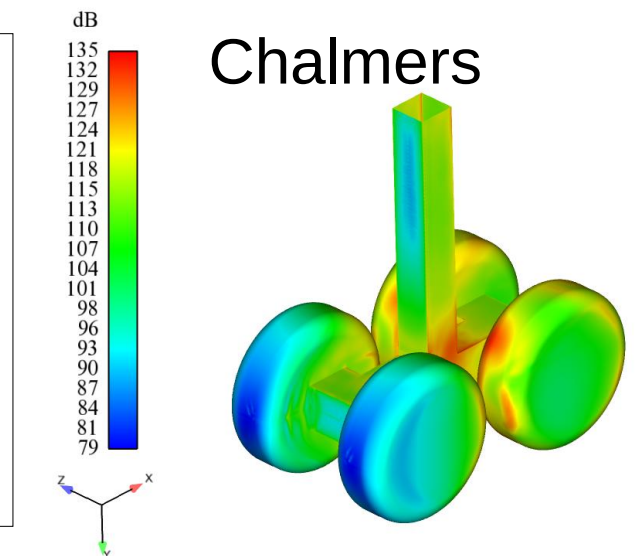
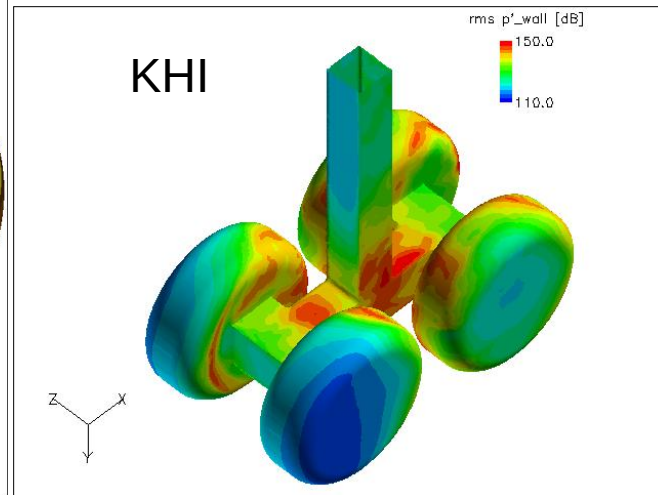
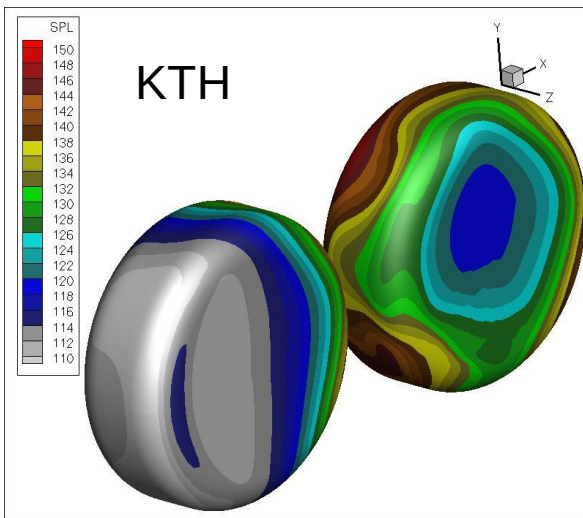
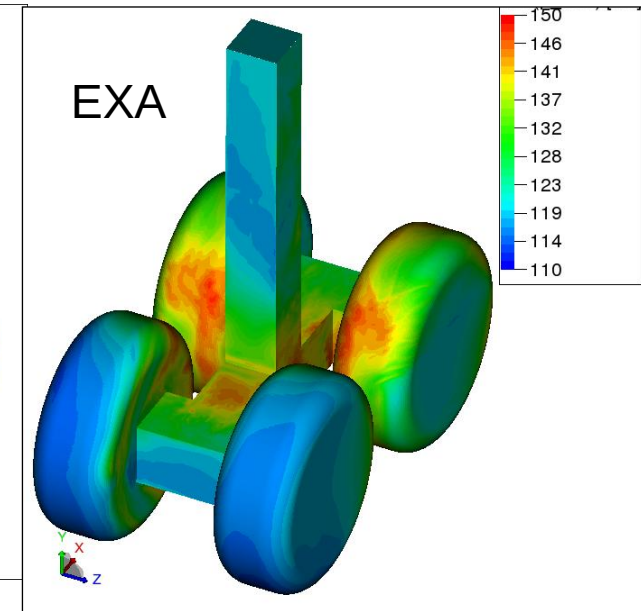
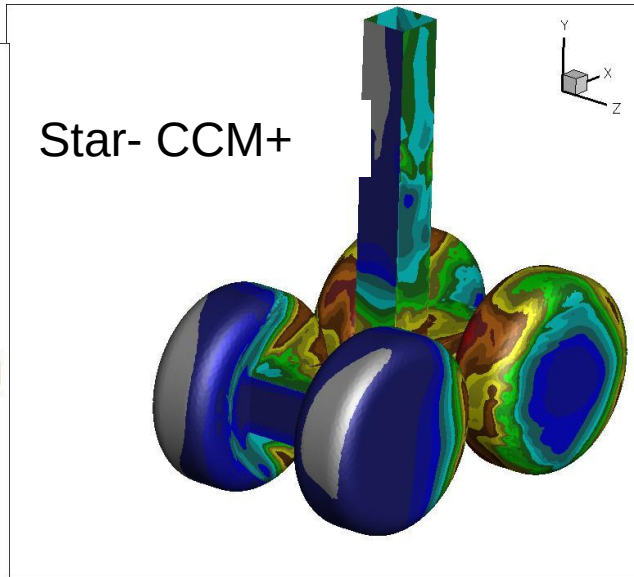
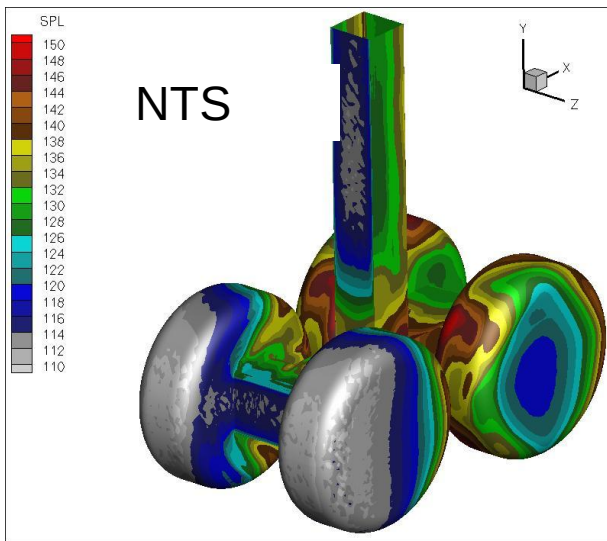
Rudimentary Landing Gear (RLG)



Overview of contributions to RLG

Org.	Turb model	Num. Scheme	Grid type	Grid count	Remarks
Boeing/NTS	DDES	Incompr. (mostly), 4 th central+ 5 th upwind/2 nd central	overset	7.6M cells	
Chalmers	PANS LES/Smagorinsky	Central +20% upwind	Unstructured hex dominated	7.8M elements	0.5% Tu
KTH	ILES	2 nd order FEM	Adjoint based AMR		
EXA	DDES/modified RNG+swirl model	Lattice Boltzmann	Unstructured Cartesian	54M/36M	0.1% Tu
CD-ADAPCO	DDES/SST	Central/upwind blend	Unstructured	29M cells/3M	$\Delta C_d < 2\%$ $\Delta C_d < 10\%$
Kawasaki, KHI	ILES	WENO7	Unstructured Cartesian	41M cells	64cpus/12 days

Surface SPL



Observations on RLG

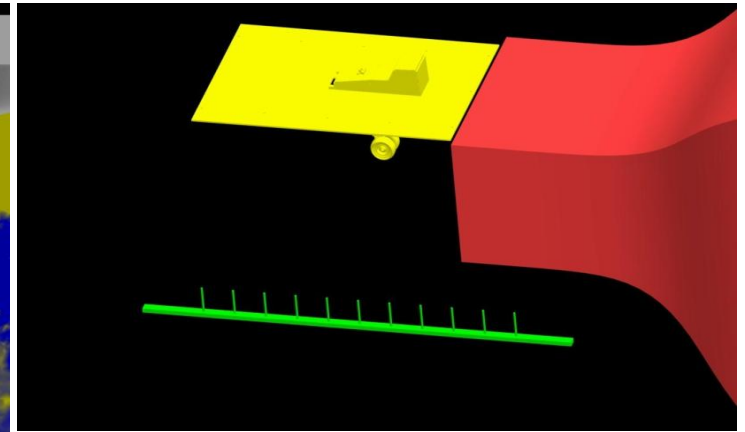
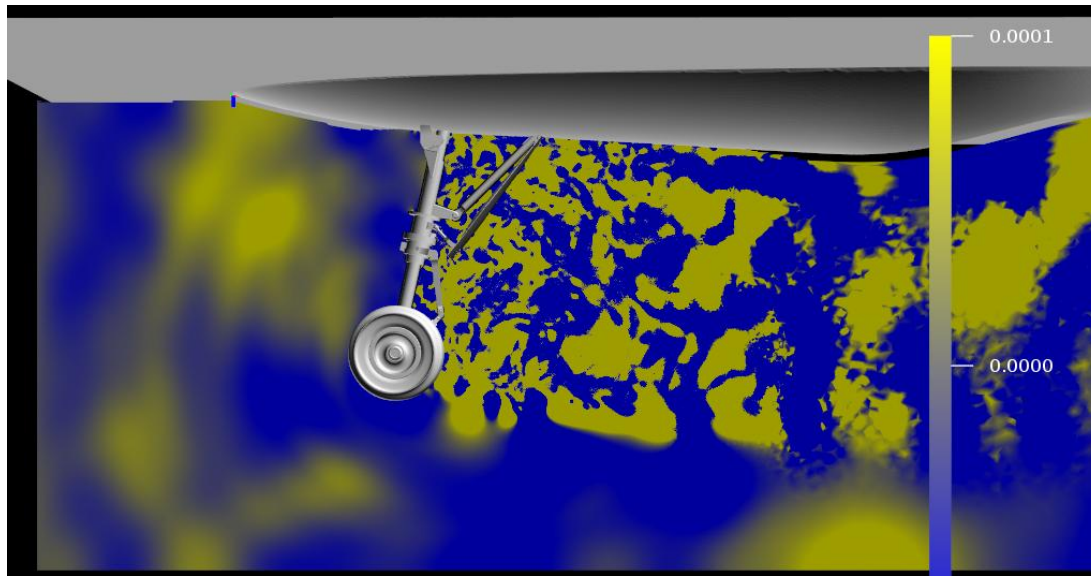


- Data and computations both evolving at this stage
 - Acoustic computations & measurements mostly undone at this point
 - No real investigation of grid/time step resolution
- 18% spread on mean drag, much less between hybrid RANS/LES methods
- RMS force fluctuations
 - Factor of 2 spread in C_L'
 - LES force fluctuations generally larger than RANS/LES
- Point measures (min & max p' values at surface) also used as metric
 - Not good choices because sensitivity to exact location too strong
- Strong interaction between turbulence generated by various gear components
- No regular vortex shedding behind post and wheels



Outlook

- **The Rudimentary Landing Gear is popular**
 - Six CFD teams from five countries, all effective
 - The experiment is lagging, but CFD can influence testing
- **The internal agreement of CFD is fair**
 - Except maybe for peak surface pressure
 - Factor of 4 difference in a small region
- **A second RLG workshop that includes radiated noise appears justified**
 - Mach ~ 0.2 preferable, and in open stream
 - Pending an experiment...
 - Probably by University of Florida
 - Need further investigation of U^6 scaling of airframe noise...



Category 4

Partially Dressed Cavity Closed Nose Landing Gear (PDCC-NLG)



Overview of contributions to PDCC-NLG

Org.	Turb model	Num. Scheme	Grid type	Grid count	Remarks
EXA	DDES/modified RNG+swirl model	Lattice Boltzmann	Unstructured Cartesian	52M/33M/16M/9M	Reasonable grid convergence of p' to 4-5KHz?
CD-ADAPCO	DDES/SST	Central/upwind blend	Unstructured	39M cells/22M/13M	P' converged to >3kHz (much more for many probes)
NASA	Hybrid RANS/LES MDDES	Roe/no limiter	Unstructured/mixed element	71M/25M/9M	P' Converged to <O(2KHz)?
Kawasaki (KHI)	ILES	WENO7	Unstructured Cartesian	O(35M) cells	64cpus/9-10 days

Steady & Unsteady Surface Pressures

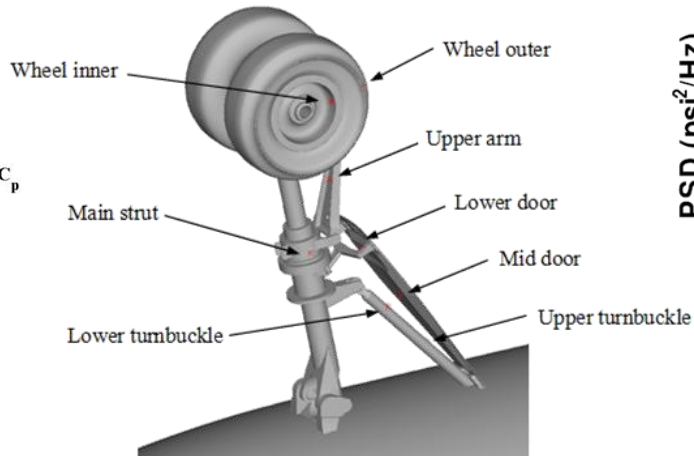
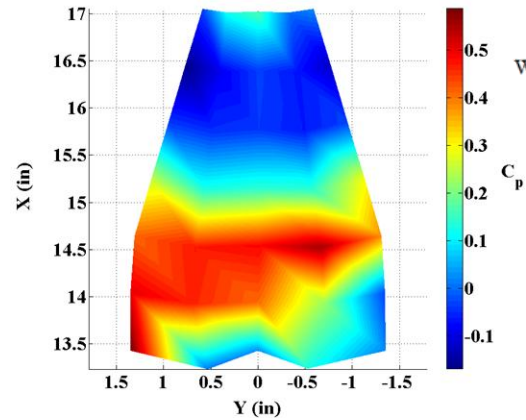
High-Fidelity 25% Scale Gulfstream G550 Nose Gear Model

D. H. Neuhart et al. [AIAA 2009-3152]

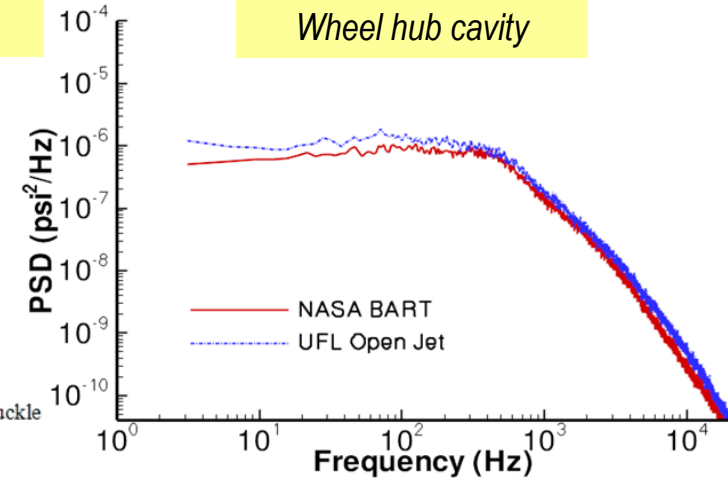
N. S. Zawodny et al. [AIAA 2009-3153]

Door C_p

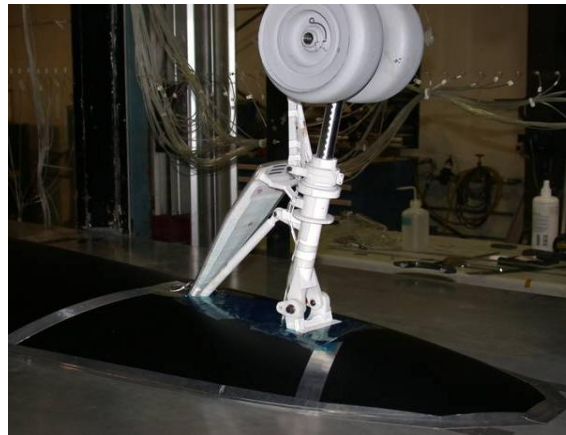
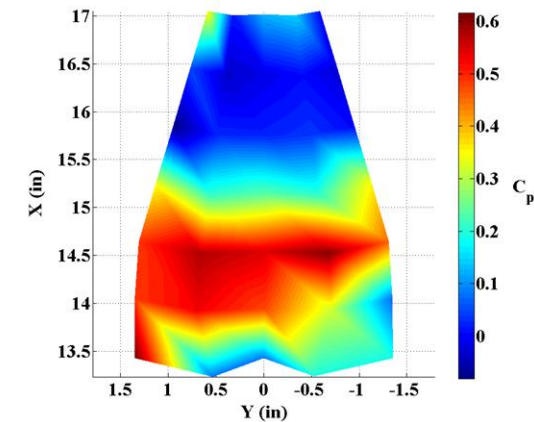
LaRC BART



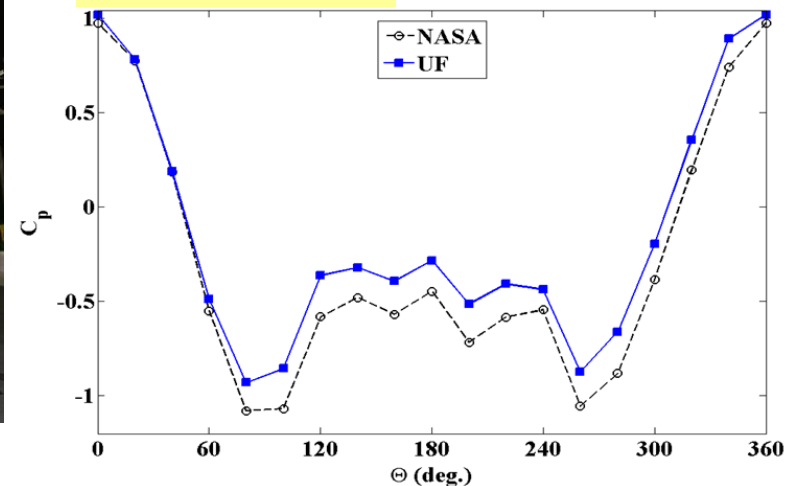
Wheel hub cavity



GAC/UF



Starboard wheel



- **Grid generation is a controlling issue**
 - No structured grid submissions
- **Requires significant computational resources**
- **Most groups did a decent job of computing the near-field flow (C_p , surface $p'(t)$, off-surface flow)**
- **Prediction of separation point on subcomponents is critical**
 - Comparison at few discrete points misleading
- **Computing the acoustic field proved more challenging**
- **Direct computations of acoustic field impractical**
 - Requires significant resources even for the case of a near far-field
 - Near field (CFD) + propagation (FW-H) as the most practical avenue
 - Lingered/serious issues with tunnel ceiling/floor effects
 - Usefulness of permeable surfaces in closed-wall tunnel configuration

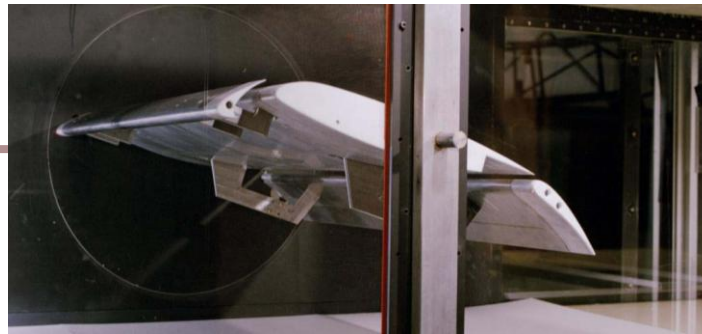
What We Wanted To Learn from BANC-I But Did Not



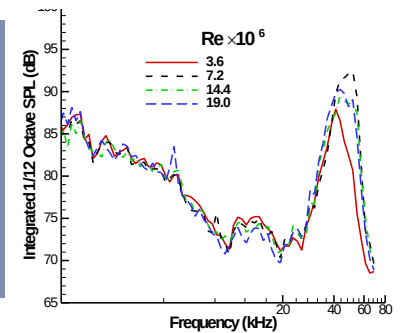
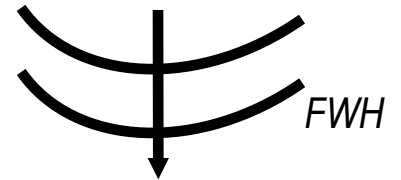
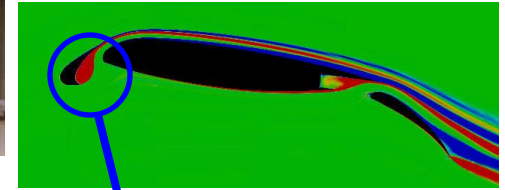
- What physics is essential to resolve to get engineering accuracy / correct trends
 - We have ideas, but no definitive evidence
 - Few even attempted to compute the noise
 - Need simulations that automatically resolve necessary features instead of relying on human intervention
- How to assess accuracy of unsteady simulations
 - Uncertainty about best measures of error/differences between unsteady results
 - Experimental data is not always available/reliable
 - Tuning to match available data does not make code general
 - Grid/time step studies are costly, rarely attempted, and convergence almost never achieved
 - How do we estimate the error and achieve confidence in our results?
- Influence of:
 - Code, Grid resolution, Time step, Domain size, Boundary conditions, Order of accuracy, Turbulence model, Human operator, Re, transition, numerical tripping
- True Best Practices instead of observations about current Standard Practices



**ONERA LAGOON
Landing Gear**



**30P30N
High-Lift System**



BANC-II

Building on BANC-I: BANC-II Workshop



- Timeframe: 2012 AIAA Aeroacoustics Conference
- Refinement of BANC-I problems (e.g., expect significant revision to problem statement for Trailing Edge Noise) + broader portfolio of noise sources
- Encourage common grids inherited from BANC-I contributions
 - Online repository for grids/solutions being arranged
- Additional problem categories (LAGOON simplified landing gear, slat-cove noise: DLR and 30P30N configurations)
 - Dataset summaries are posted on DG website
<https://info.aiaa.org/tac/ASG/FDTC/DG/BECAN.aspx>



- Stronger collaborative element:
 - Dataset development (e.g., DLR-ONERA, NASA-Embraer-JAXA)
 - Workshop planning and organization
 - Workshop computations (teaming arrangements)
- Isolate code to code variability associated with the acoustic propagation phase by assessing propagation separately
- Exploring potential new element targeting the involvement of modeling community
 - Provide improved physical insights, refinement/assessment of reduced-order models using in-depth data associated with BANC configurations

BANC-II Planning



- Everyone is welcome to participate
- Interested parties should fill out the BANC-II survey
 - Survey targets input regarding interest in participation, workshop dates, problem selection, workshop, format, volunteer contributions...
 - To access the survey, contact
Meelan.M.Choudhari@nasa.gov
- BANC-II announcement will be included in the Call for Papers for the 2012 Aeroacoustics Conference in Minneapolis
- An informal session is planned for the 2011 Aeroacoustics Conference in Portland to update BANC-II participants

