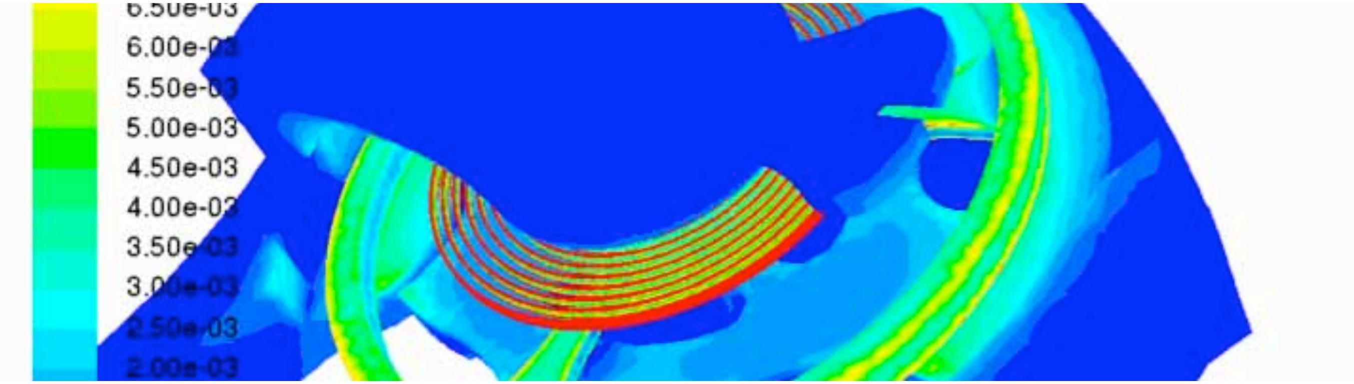

Industrial Applications of CFD : From Formula 1 to Watch Design

Patrick Haas, Prof. HES

L'avenir est à créer

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www.cmefe.ch

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SWISS UNIVERSITIES OF APPLIED SCIENCES AND ARTS

- 7 Universities
- + 2 private
- 80' 000 Students

hepia
(Geneva)

100 YEARS OF FLUID MECHANICS AT HEPIA

1900 : First activities in thermics and aerotechnics. « Marc Birkigt years ».

1940 : Activities in sailing and civil engineering.

1970 : design and building of wind tunnels of bigger sizes.

1980 : Pulsated Over Heated Water Rocket POHWARO

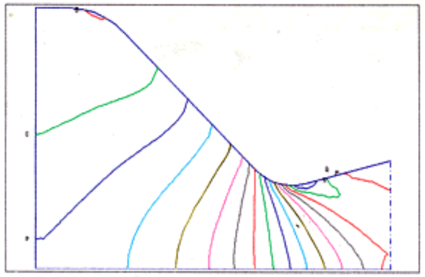
1984 : development of an implicit code for transonic flow simulation. Begining of CFD use at hepia-cmefe !

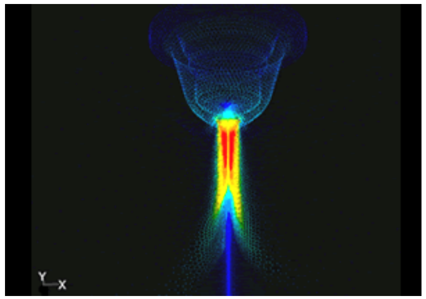
1987 : Acquisition of the Hispano test facilities in Pont-Butin (Geneva).

1995 : Design and production of the big wind tunnel at Pont-Butin.

2003 : Investments in the calculation power of the group.

2005 : A great part of the financial ressources comes from local industry.





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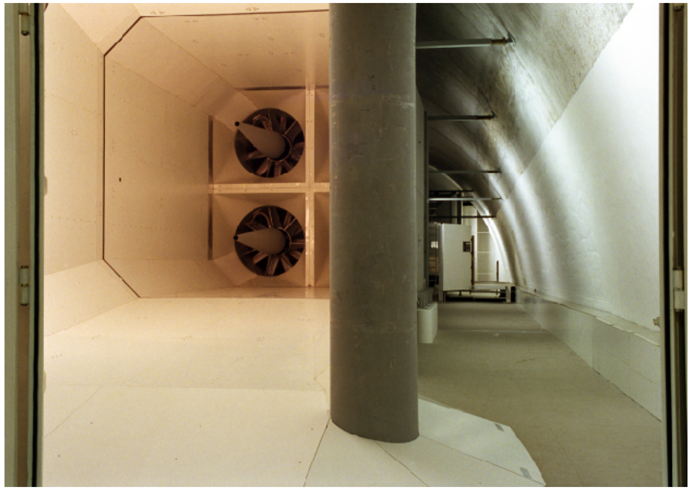
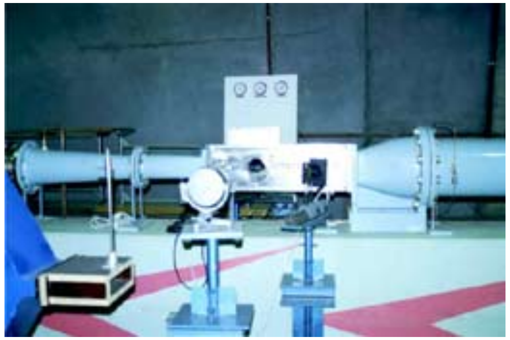
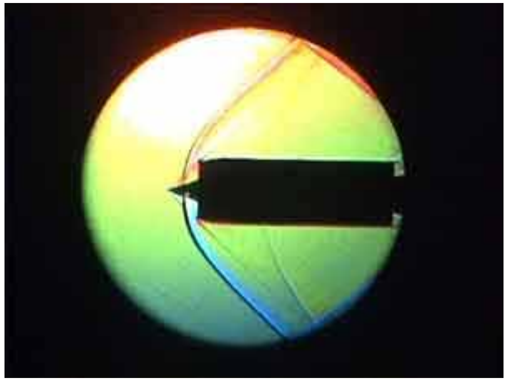
CMEFE
THE HEPIA FLUID DYNAMICS GROUP



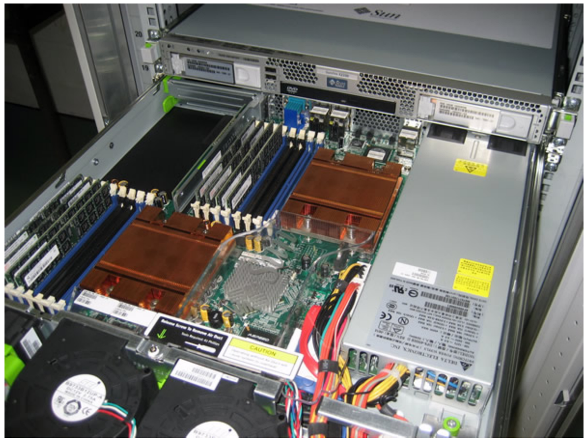




HEPIA-CMEFE COMPUTATIONAL RESSOURCES

- 7 Workstations 126 Gb RAM, 16 cores 3.2 GHz
- 224 Cores Calculation Server, 3 Gb / cores RAM, Infiniband Interconnects
- 70 Tb HD RAID5 storage
- ANSYS CFD Associate Licences
- OpenFoam (Open source CFD)
- In house developed codes (C, Fortran)

ANSYS Associate



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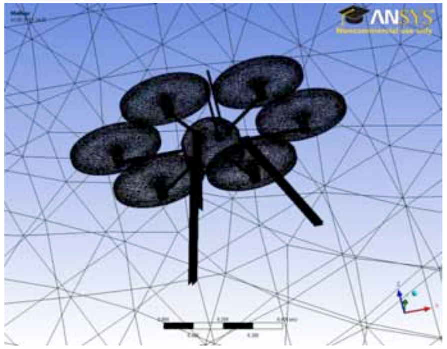
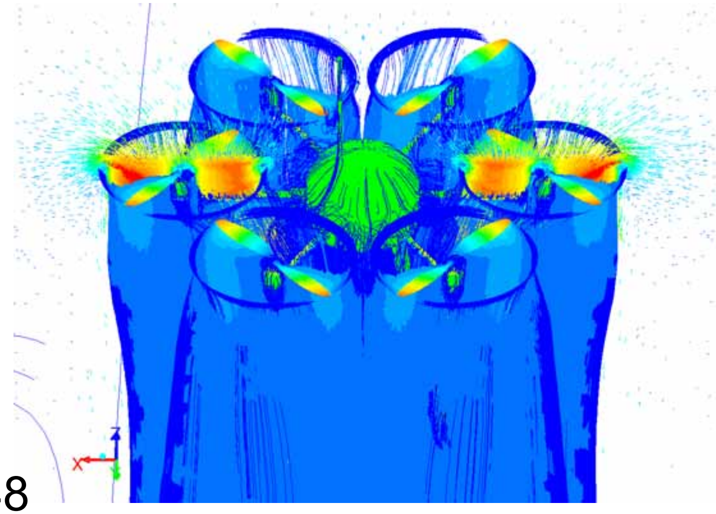
HEPIA UAV FOR AIR POLLUTION MEASUREMENTS





- 15 Million cells
- 10 days calculation on 48 cores (0.00001 s time step)

Propeller speed (t/min)	Lift CFD (N)				Lift wind tunnel (N)
Time step (s)	0.01	0.0001	0.00002	0.00001	
3'810	10.9	17.9		18.4	22.0
4'202	12.7	21.3		22.5	25.0
4'584	15.4	25.4			30.2
4'966	15.8	29.6			38.3
5'348	16.0	35.6	36.5	36.5	46.2
5'730	24.7	51.9	42.0		50.5

Figure 14. Lift generated by the UAV propellers and time step sensibility.

WATER FOUNTAIN GENEVA

Vue depuis le toit d'hepia, le 6 mai 2014
(pendant la période d'essais de la nouvelle buse)

- 2 pumps 16 bars
- 2 x 500 kW = 1 MW nominal power suply (720 kW effective)
- 500 lts/sec water

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WATER FOUNTAIN GENEVA

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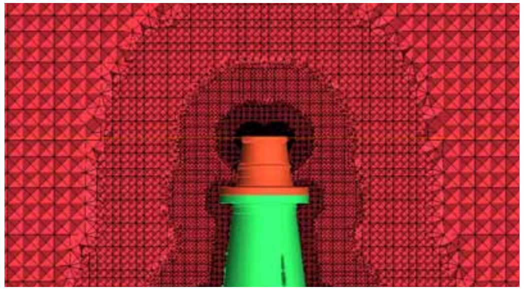
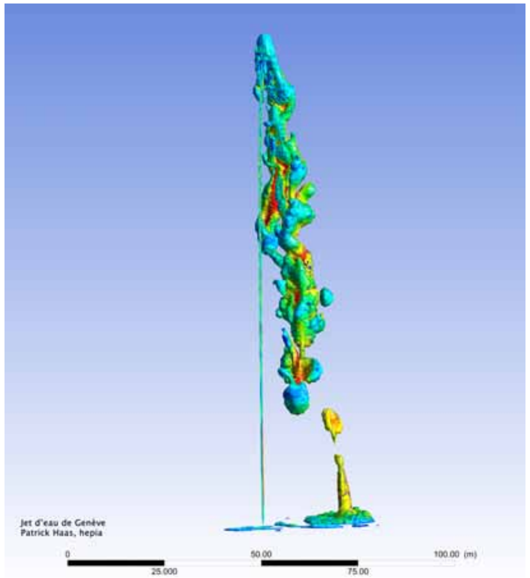
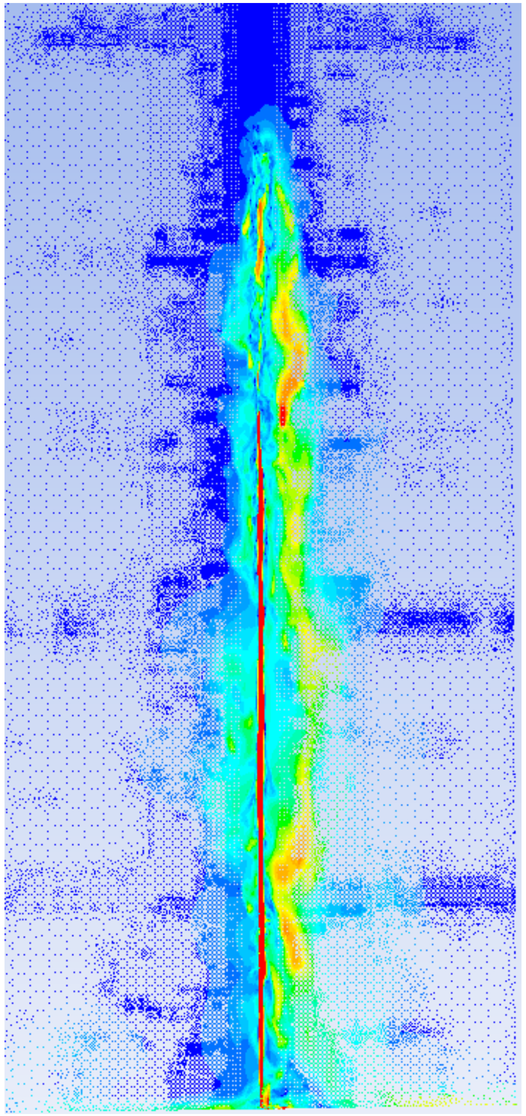
<u>Objective</u> : Reduction of power (flow volume) with same heigth.





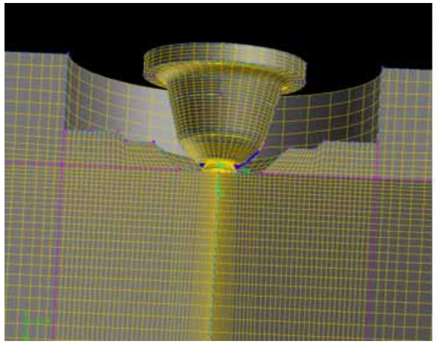


- Model SIMPLE, ANSYS 13
- Catia CAD
- ICEM Mesh patch independent
- 22 Millions cells
- Domain : 60 m x 60 m x 150 m
- RANS k−e RNG, VOF
- Standard wall functions
- 14 days calculation on 48 cores for 10 sec real time

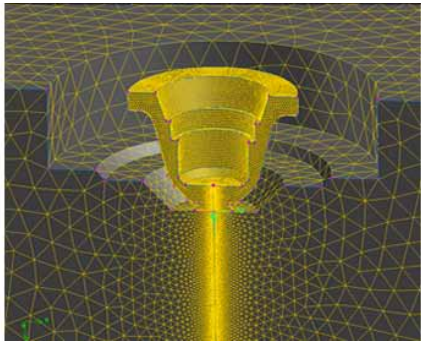
Wind 0 (m/s)	New nozzle	Existing nozzle
CFD analysis	126 m	136 m
Measurements	120 m	140 m

Wind 2 (m/s)	New nozzle	Existing nozzle
CFD analysis	118 m	134 m
Measurements	115 m	135 m

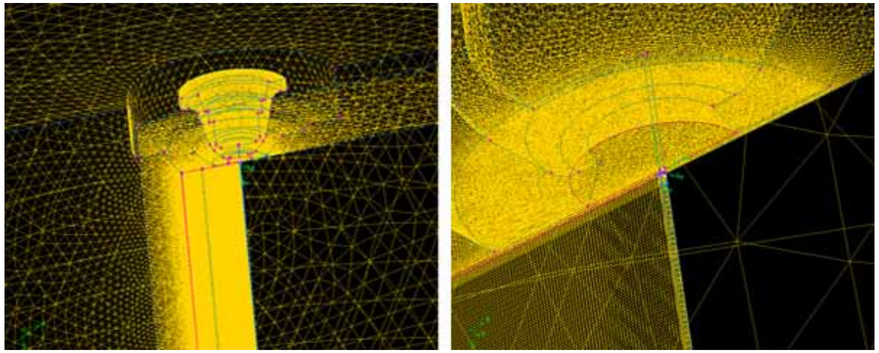
ELECTRO-MACHINING (EDM) PROCESS HYDRODYNAMICS



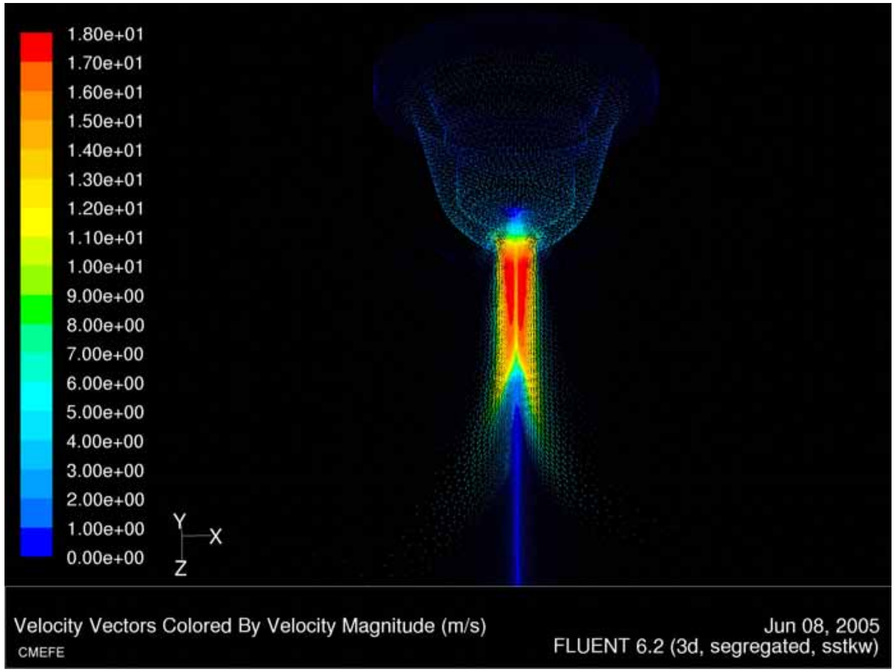
Map mesh (hexahedron)



Tgrid patch conform mesh (tetrahedron)



Tgrid patch conform mesh for tank and nozzle (tetrahedron), Cooper hexaedron for the slot and gap.



- Particles trajectories calculation
- Injection nozzle design for a faster production in wire EDM and die sinking EDM

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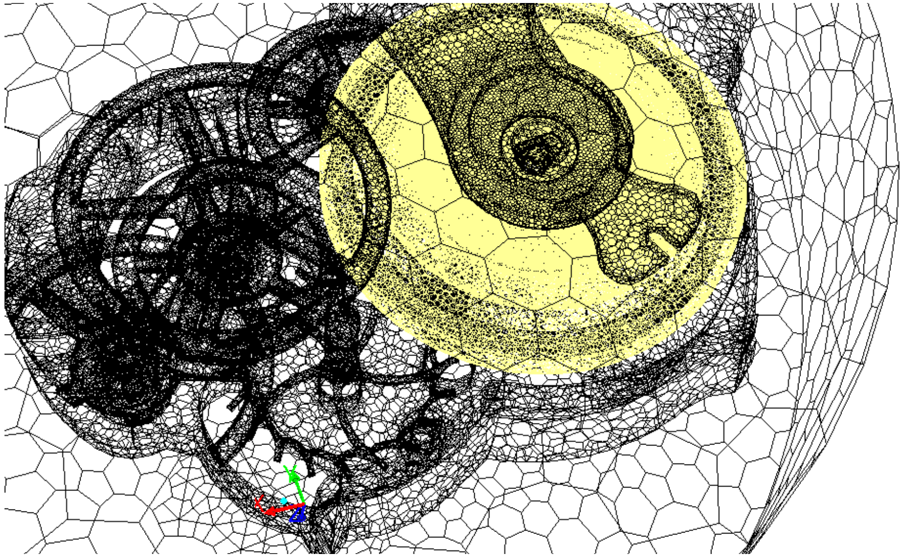
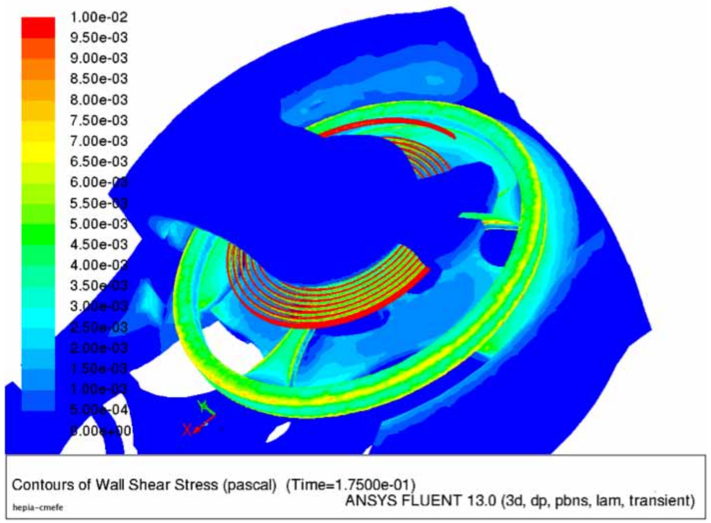
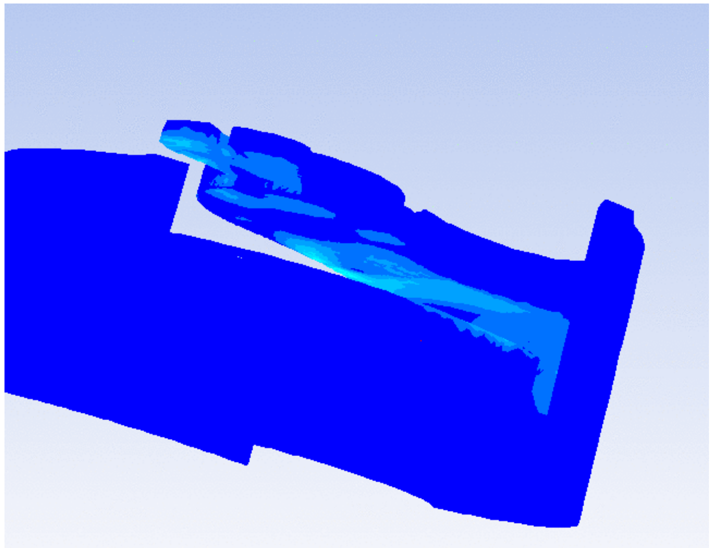
MECHANICAL WATCHES DESIGN







- Polyhedron elements
- Wheels in rotation and interfaces
- 4 Hz oscillating movement
- Moving parts aerodynamics (shears, pressures)
- How the energy is loss in a watch ?
- How to increase eficiency, reserve ?

EXAMPLE OF WORKING METHOD
MOTORSPORTS AERODYNAMICS

Since many years hepia is working on motorsports aerodynamics :

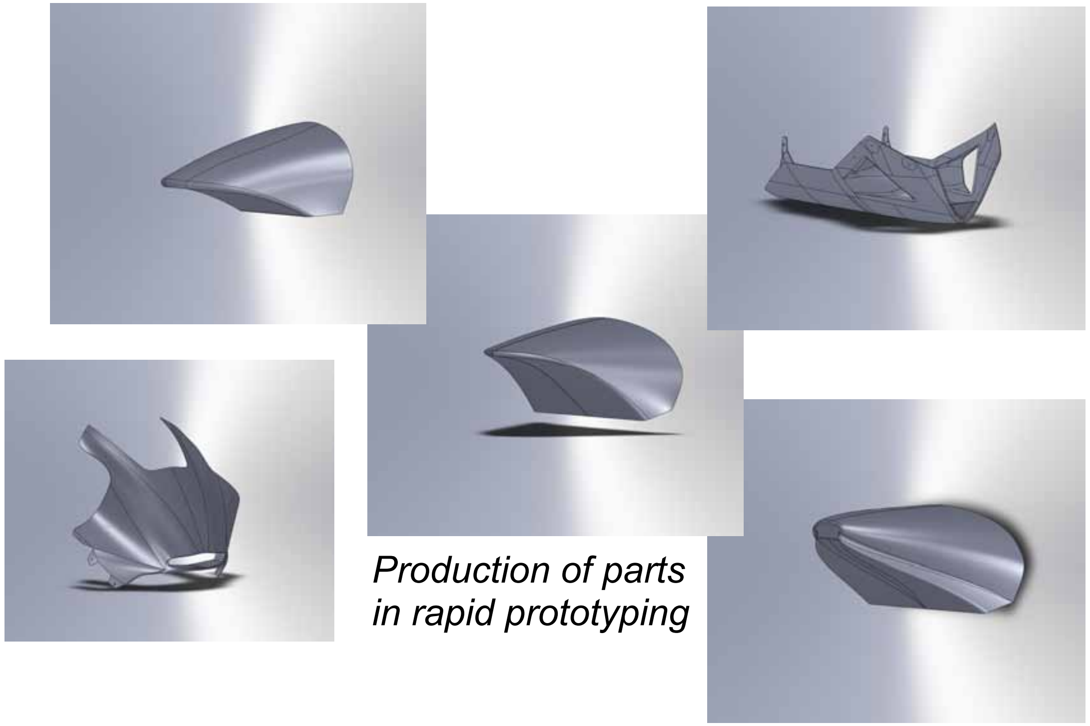
- Egli Motorradtechnik (1985) Bachelor thesis
- Motos ROC Annemasse (1992) Bachelor Thesis
- ASM Formula 3 (2006)
- Eco-marathon Shell : Consomini (2003-05), Biomobile.ch (2005 - actual)
- Motostudent PoliTo Turin (2011-12)
- Moto2 NCS Rapid Inside Modena (2011)
- Audit of the Formula 1 teams (2010 – 2013)
- MotoGP Akira (2014 - actual)
- Moto2 Tech3 (2014)
- Moto2 Technomag CarXpert Suter and Kalex (2014 - actual)
- Vyrus M2 (2016)

How CFD advantages can be applied to these hepia activities ?

THE TRADITIONAL WORKING METHOD

- Based on experience and feeling, production of parts in rapid prototyping
- Use of a motorcycle rigid support and a 6 components balance
- Rotation of the front wheel using a rolling belt

CAD of the motorcycle



Production of parts in rapid prototyping

THE TRADITIONAL WORKING METHOD

Experimental analysis of the moto2 Ri211 from Rapid Inside NCS (Modena) in 2011. Air box inlet design.

- Until a recent time such study was done exclusively by the use of wind tunnel measurements or on track !
- Offently, only the global effect is measured (i.e. the total forces and moments).

Expensive investigation time is needed to get complex phenomenon understanding.

A MUCH EFFICIENT WAY TO WORK : EXAMPLE WITH THE FORMULA 1 TEAMS

Formula One Teams Association

- From 2010 to 2013 hepia worked as partner of the Formula One Teams Association (FOTA)
- Patrick Haas and Roberto Putzu are team auditors in charge of the « *Aerodynamic testing and CFD simulation Regulation* »

Force India

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FORMULA 1 WIND TUNNELS

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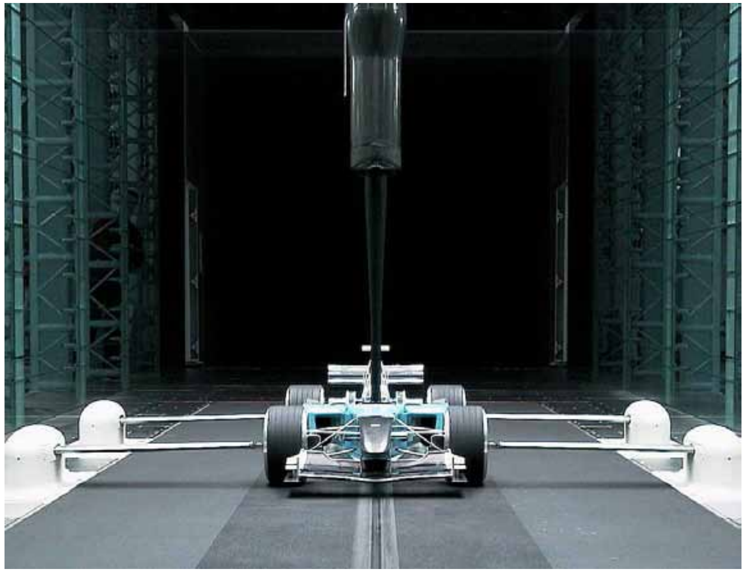


Some Formula 1 wind tunnels

FORMULA 1 WIND TUNNELS

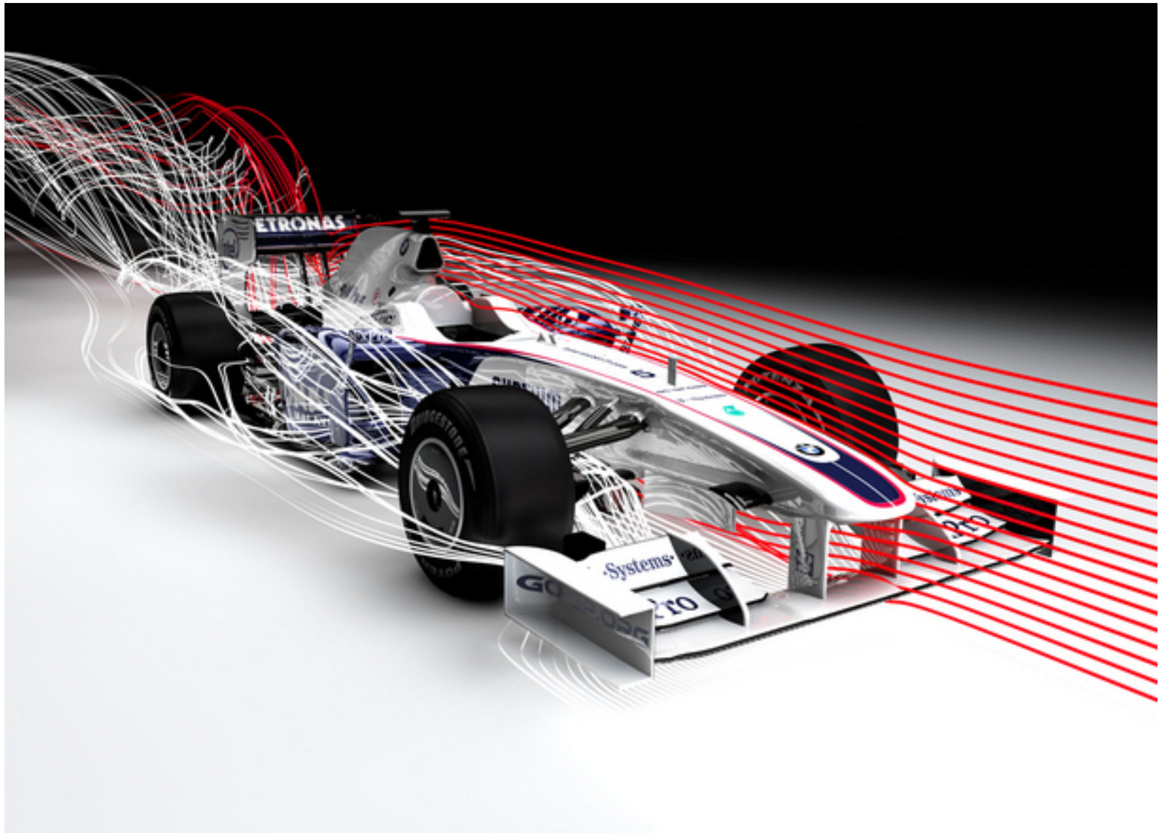
« Aerodynamic Testing Restrictions (FOTA) »

- Regulation adopted to reduce costs!
- 60% max. model scale
- 50 m/s max air speed
- Rolling belt
- Boundary layer succion
- Tests for several angles (pitch, yaw)
- More than 500 complete tests a month (all angles) in addition to CFD

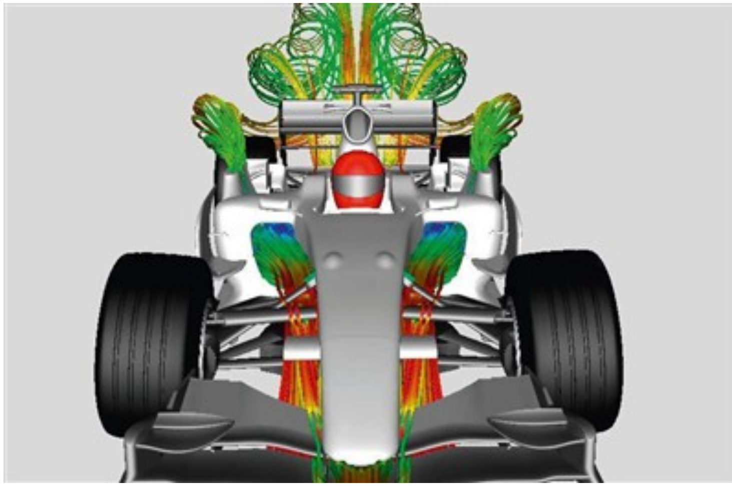
A test every 30 minutes !

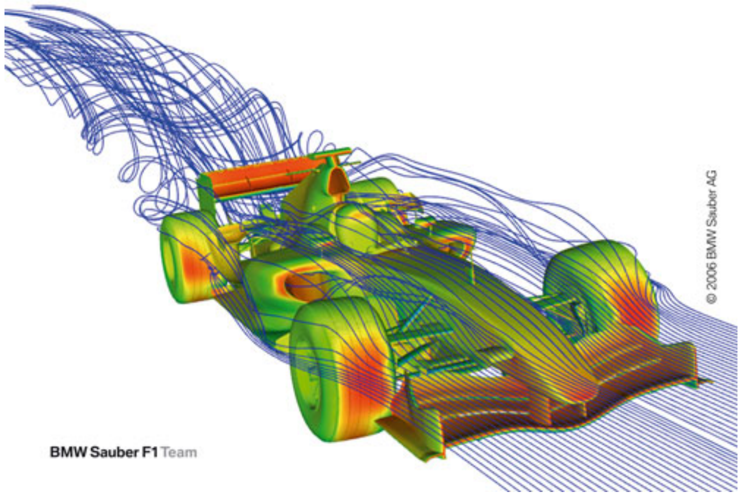
Engineers need to understand well the flow structure
and to imagine a lot of potential solutions.

FORMULA 1 CFD METHODS



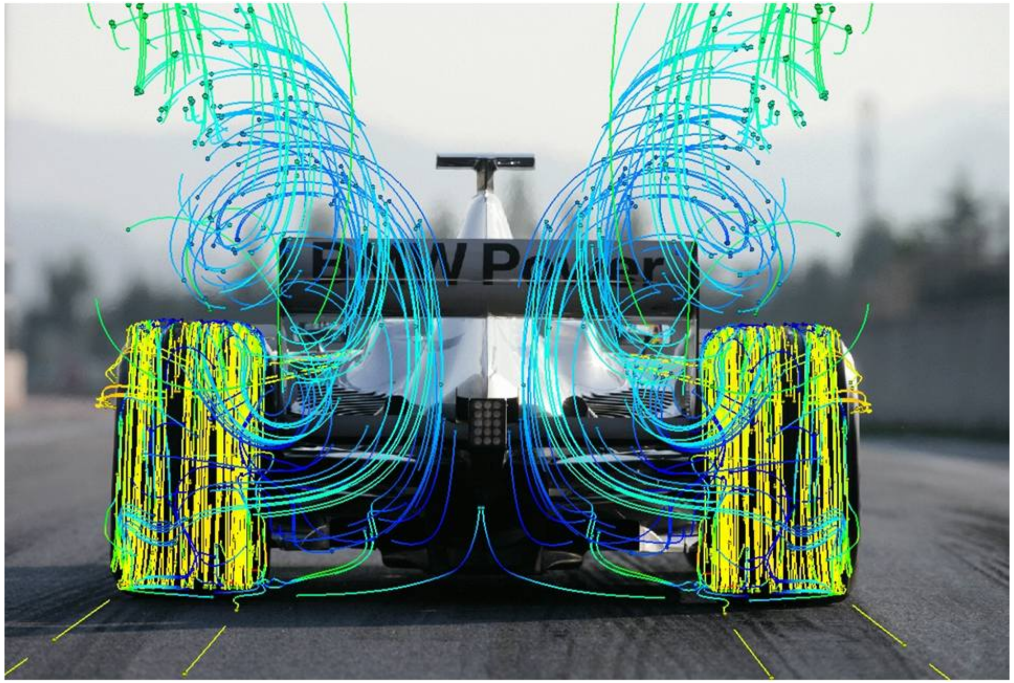
Sauber





FORMULA 1 CFD METHODS

« Aerodynamic CFD Restrictions (FOTA 2013) »



Sauber

- The number of operations in a period of 2 months is limited
- Up to 18 h CPU time on a server of hunderth of cores per simulation
- Up to 1’500 CFD simulation per month

Up to 50 simulations full car per day !

CFD CAPABILITIES OF THE FORMULA 1 TEAMS

Albert HPC server, Sauber

- Commercially available codes (ANSYS Fluent, Star CCM+)
- Finite volume approach
- Highly parallelized computer of 64 bits processors
- Servers with up to 6'000 cores
- Up to 18'000 Gb RAM
- Infiniband DDR 48 Gbit/s interconnections or better
- Approx. 100 kW electrical suply
- Approx. 150 kW cooling tower (condenser)

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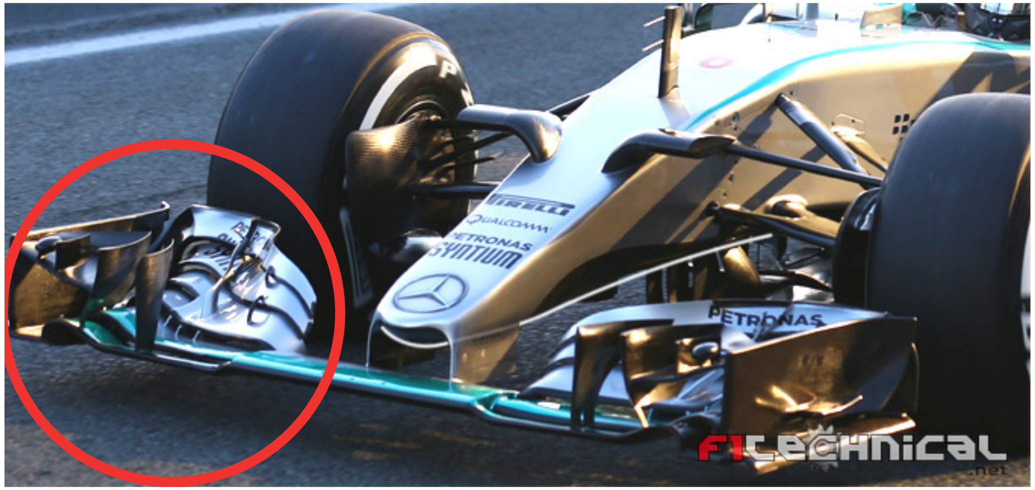
WHAT CAN BE LEARNED FROM THE FORMULA 1 TEAM WORK?



Mercedes AMG F1 WA06, 2015

Ferrari SF15T, 2015

1. CFD intensive computations:

- CFD shows all quantities everywhere without perturbing the flow at the time scale you want!
  Complete and detailed flow understanding → New ideas!
- Complex geometry optimisations – Parameter studies

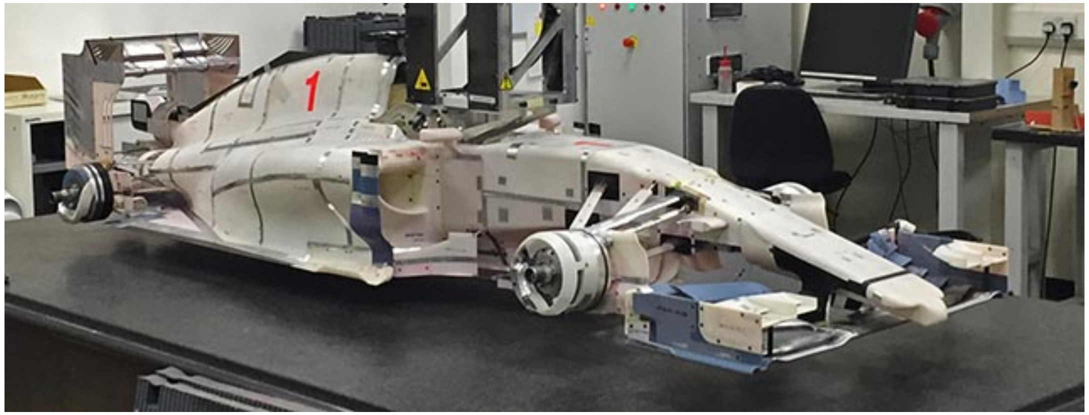
WHAT CAN BE LEARNED FROM THE FORMULA 1 TEAM WORK?

2. Wind tunnel tests:

- Instrumented models (balances, PSI, motorized wheels, suspensions, ecc.)
- Rapid prototyping parts on a steel body
- Exceptional methodology and work organization

3. Tests on track:

- Aspect ratio and size effects
- Hypothesis validation



Marussia 2015

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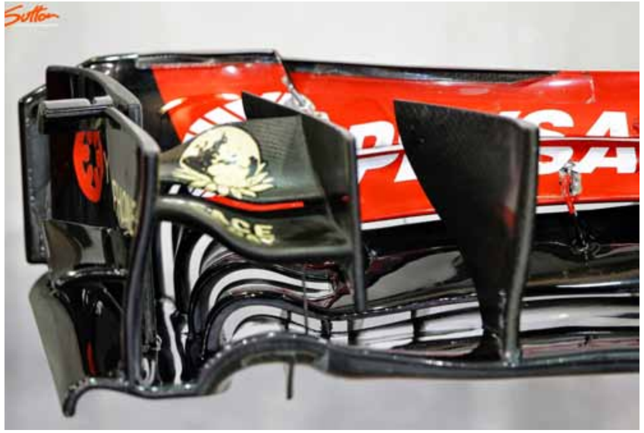
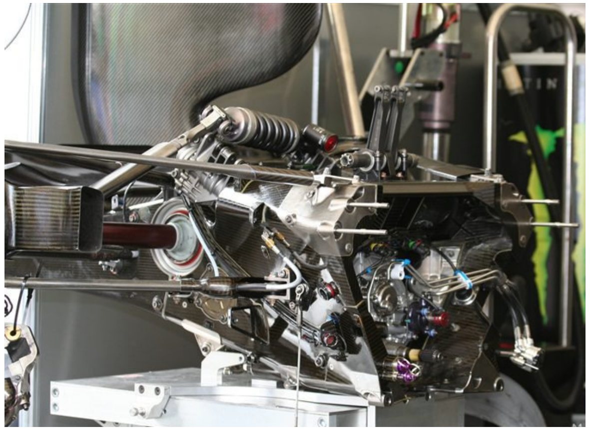
THE RESULTS OBTAINED BY THE FORMULA 1 TEAMS ARE REALLY IMPRESSIVE

The methodology is used for the design of all significant systems and leads to the most impressive results industry never reached.





- The aerodynamics down force is 3’000 kg at 300 km/h
- The engine output is approx. 800 HP for an engine mass of 95 kg
- The total mass of a F1 is 600 kg (regulation)
- A Formula 1 brakes from 200 km/h to 0 in 2.9 sec on 65 m
- The Formula 1 teams develop the KERS system in a few months…

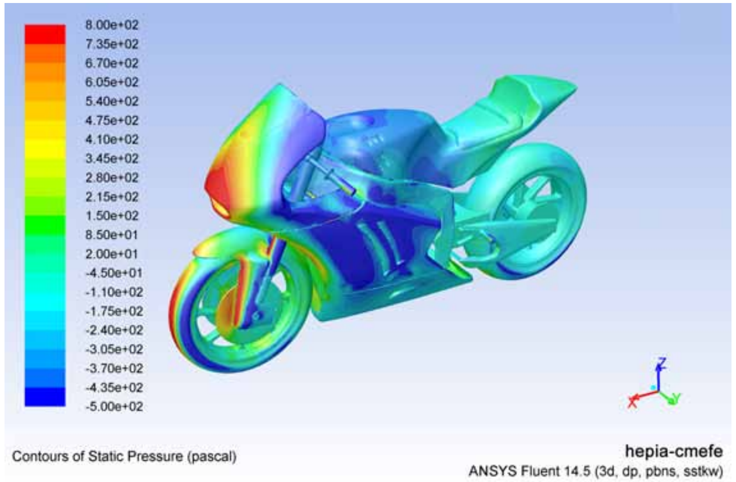
CFD and other simulation technics are major tools used by the teams.

THE HEPIA MOTO2 AERODYNAMIC PROGRAM

1. **Wind tunnel tests with 50% scale models**
   - Difficulties having the bike for a long time in the wind tunnel (no second bike allowed in moto2 regulation)
   - Aspect ratio (front area / test section)
   - Costs

2. **Wind tunnel tests at full scale**
   - Pilot training and position, seat definition
   - Validation of CFD results
   - Continuity with the past (known results and effects)

3. **Simulation CFD**
   - Flow understanding
   - New ideas, aerodynamic program definition
   - Motor cooling and thermal analysis



THE HEPIA MOTO2 AERODYNAMIC PROGRAM

4. On track aerodynamic drag evaluation

- Full scale
- Complete motorcycle (the true one!)
- Made by torque measurement on gearbox shaft
- Job done using a motoGP to investigate the effect of the aspect ratio

Italy Grand Prix 2015

5. Race results analysis

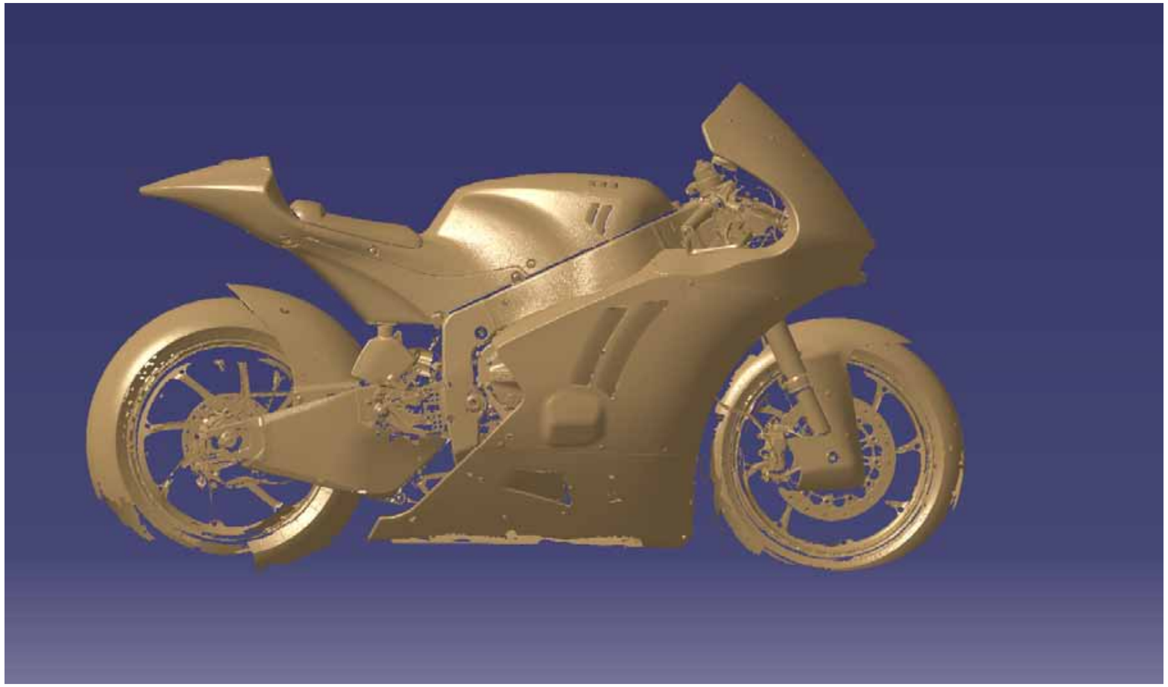
- ECU logger data analysis

→ Each chapter is used for their advantages in a way to avoid weakness of the other ones. You need all these approaches together to go to the success!

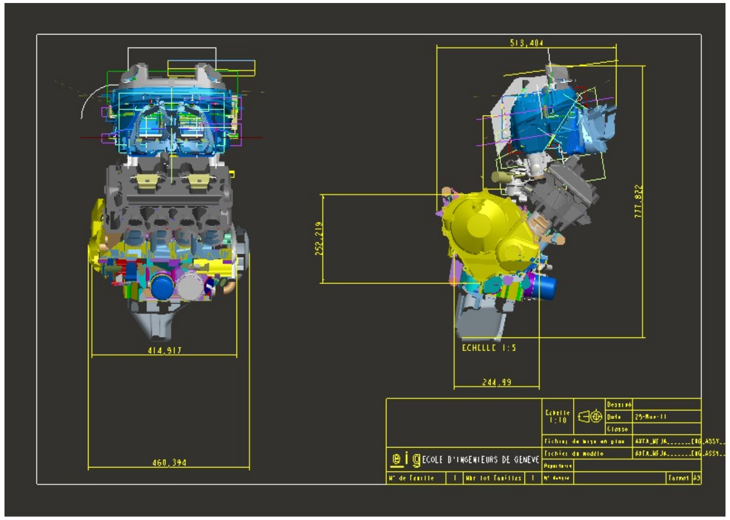
The objective is a real increase of performances during the races, i.e. on track!

WIND TUNNEL TESTS WITH 50% SCALE MODELS

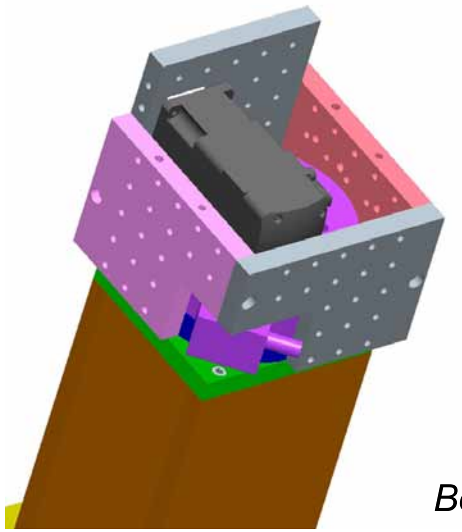
CAD Model Development



Scan 3D, CAD, ecc.



Motor Honda 600 cm3



Body

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WIND TUNNEL TESTS WITH 50% SCALE MODELS

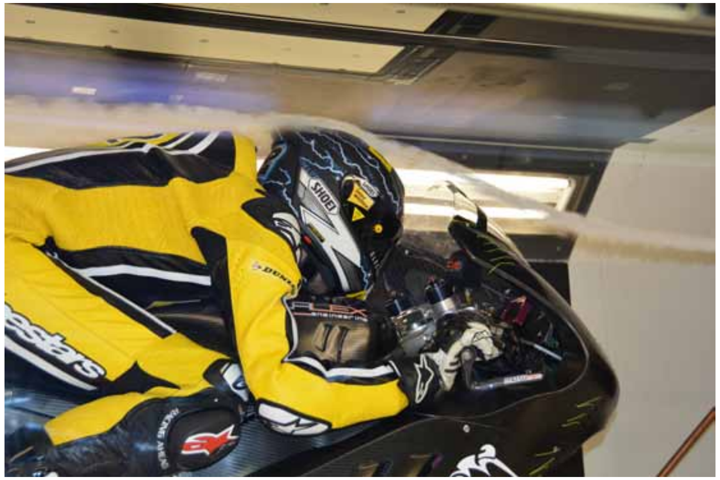
Model production and instrumentation

Fairing

Motorized wheel

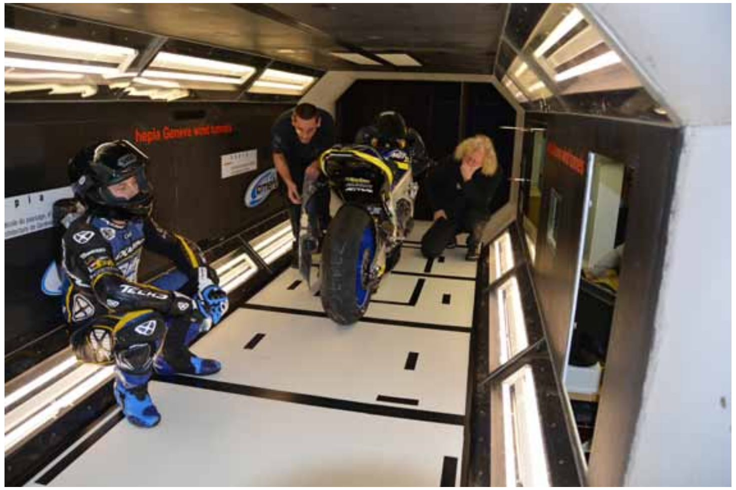
Model assembly

WIND TUNNEL TESTS AT FULL SCALE



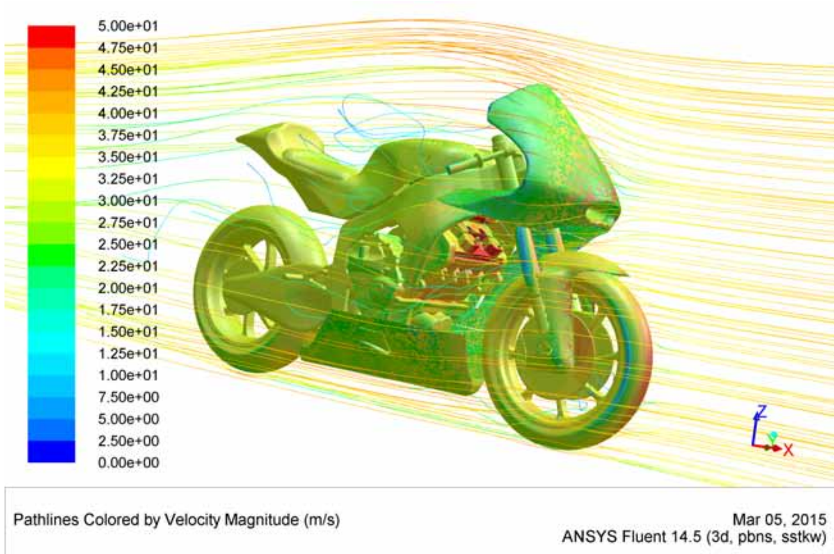
T. Lüthi

Suter



Tech3

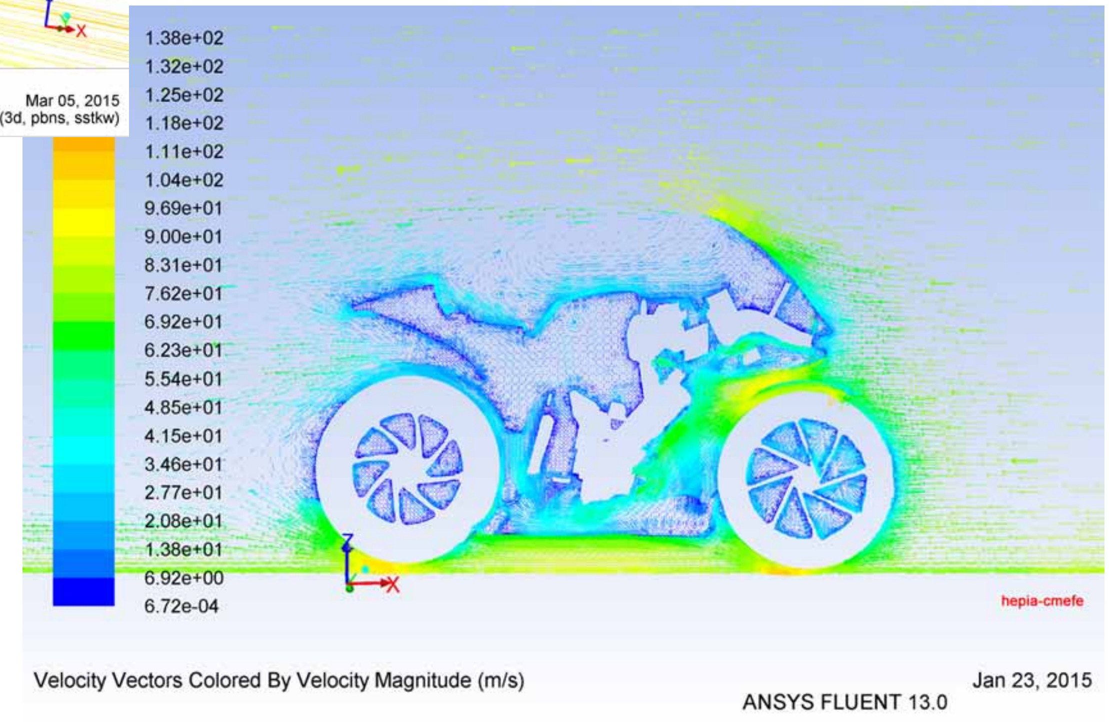
CFD SIMULATIONS



Objectives

- External and internal aerodynamics
- Drag optimisation
- Thermal exchange

- Radiator as an anysotropic porous media
- Rotating wheels with mesh interfaces



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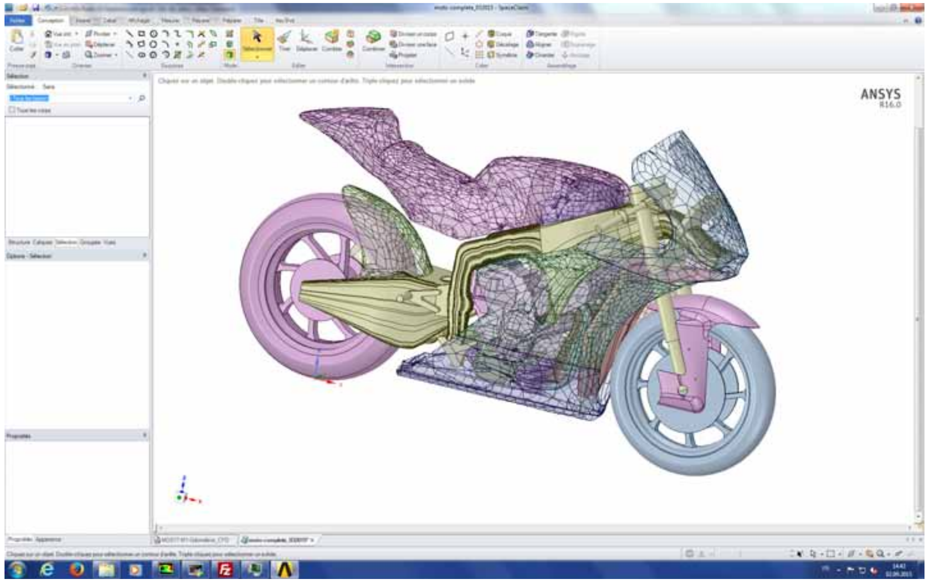
CFD SIMULATIONS

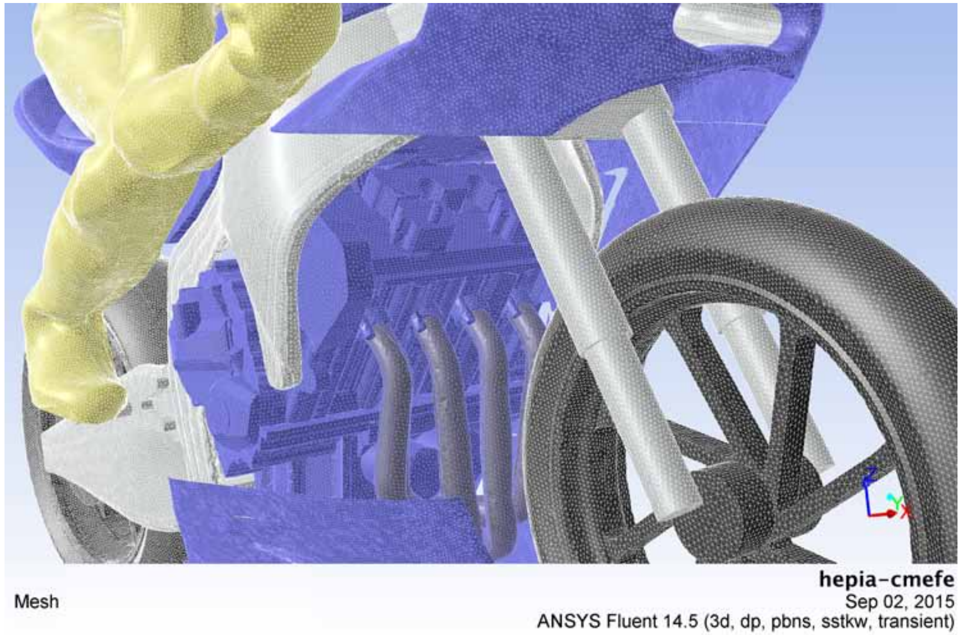


Modeler

- Catia V5
- ANSYS SCDM (Space Claim Design Modeler)

Mesher

- ANSYS ICEM
- Workstation 16 cores, 126 Gb RAM
- 30 millions cells



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CFD SIMULATIONS

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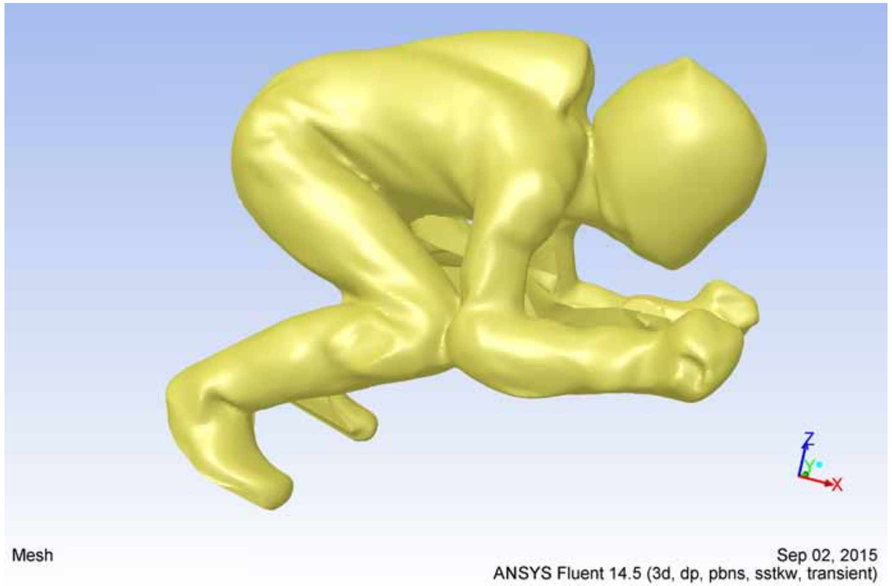
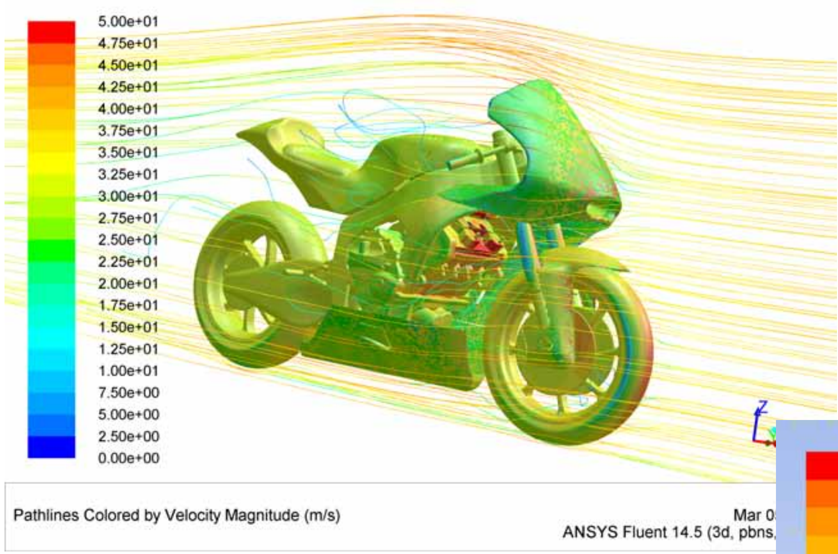
Scan of the pilot

- Hand scanned (fast)
- Dominique Aegerter
- Correct positions
- All suit and helmet details!



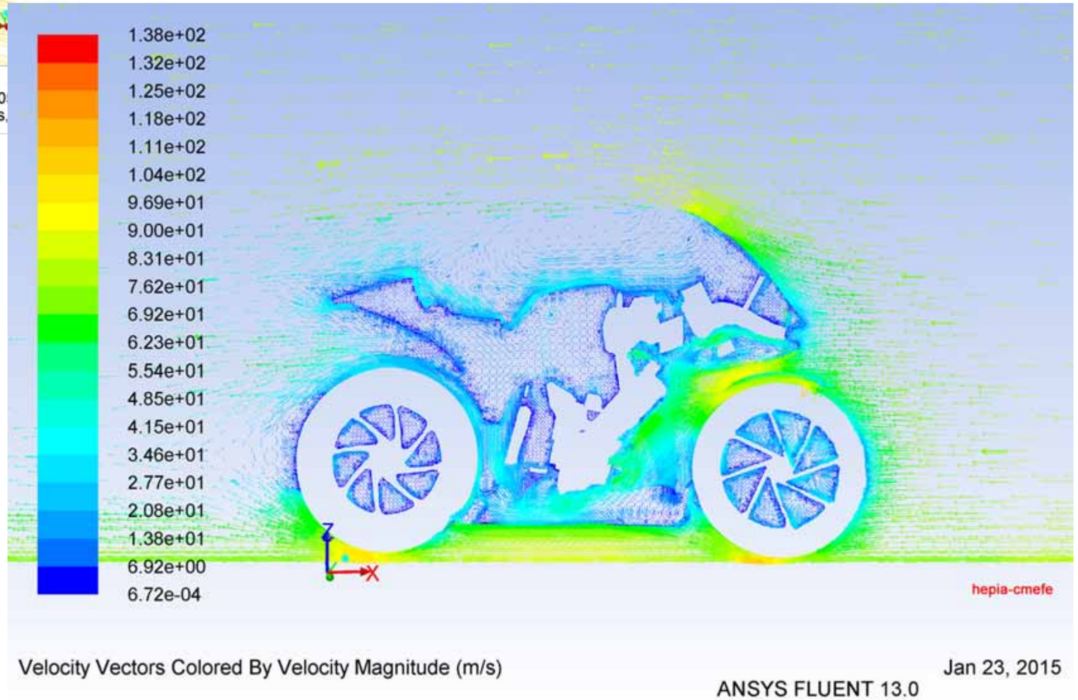
Dominique Aegerter 77 and Kalex Moto2

CFD SIMULATIONS

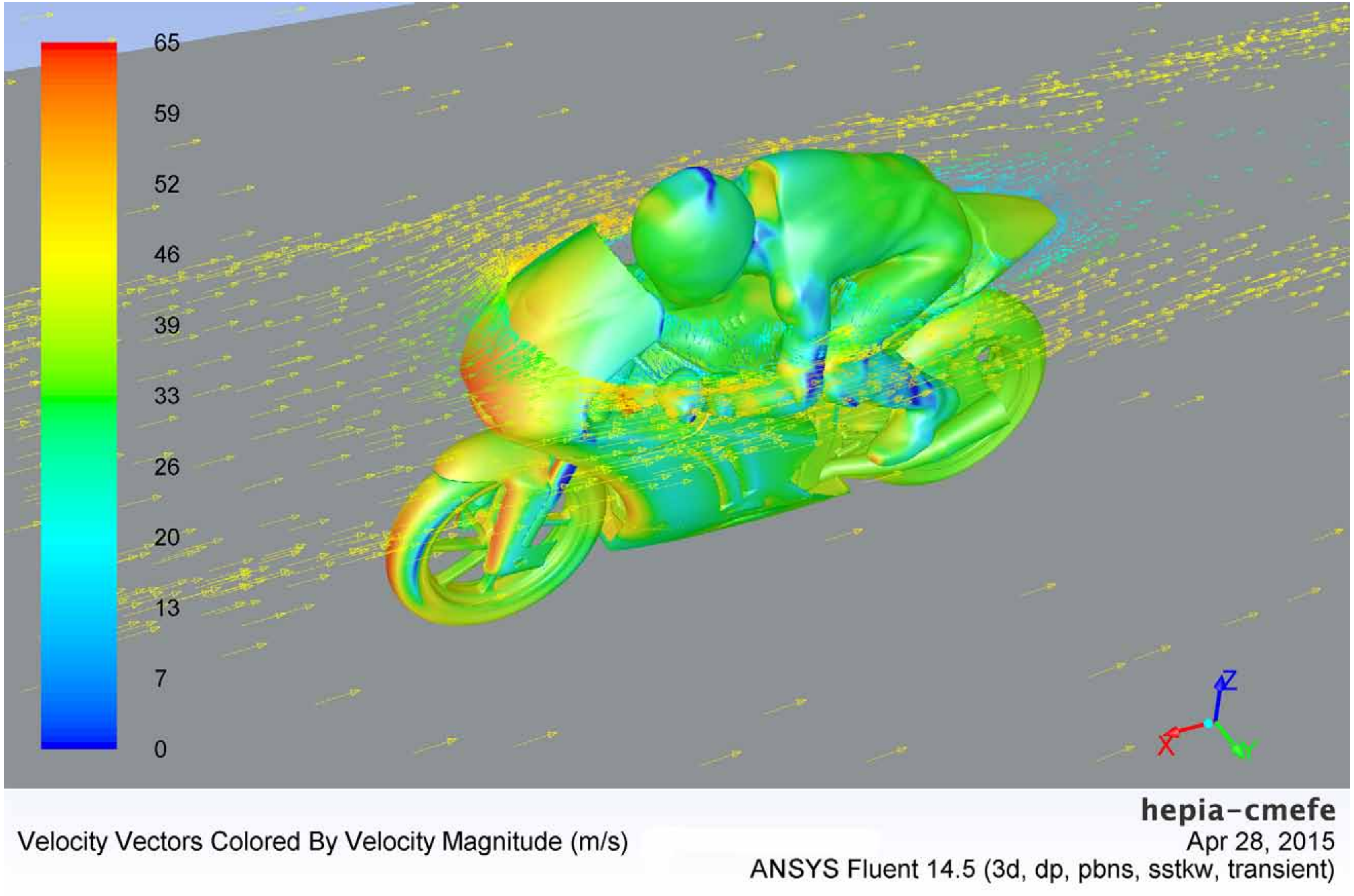


Solver

- ANSYS CFD Fluent
- Server 224 cores, 3 GHz
- Pressure based solver
- Turbulence SST – kw

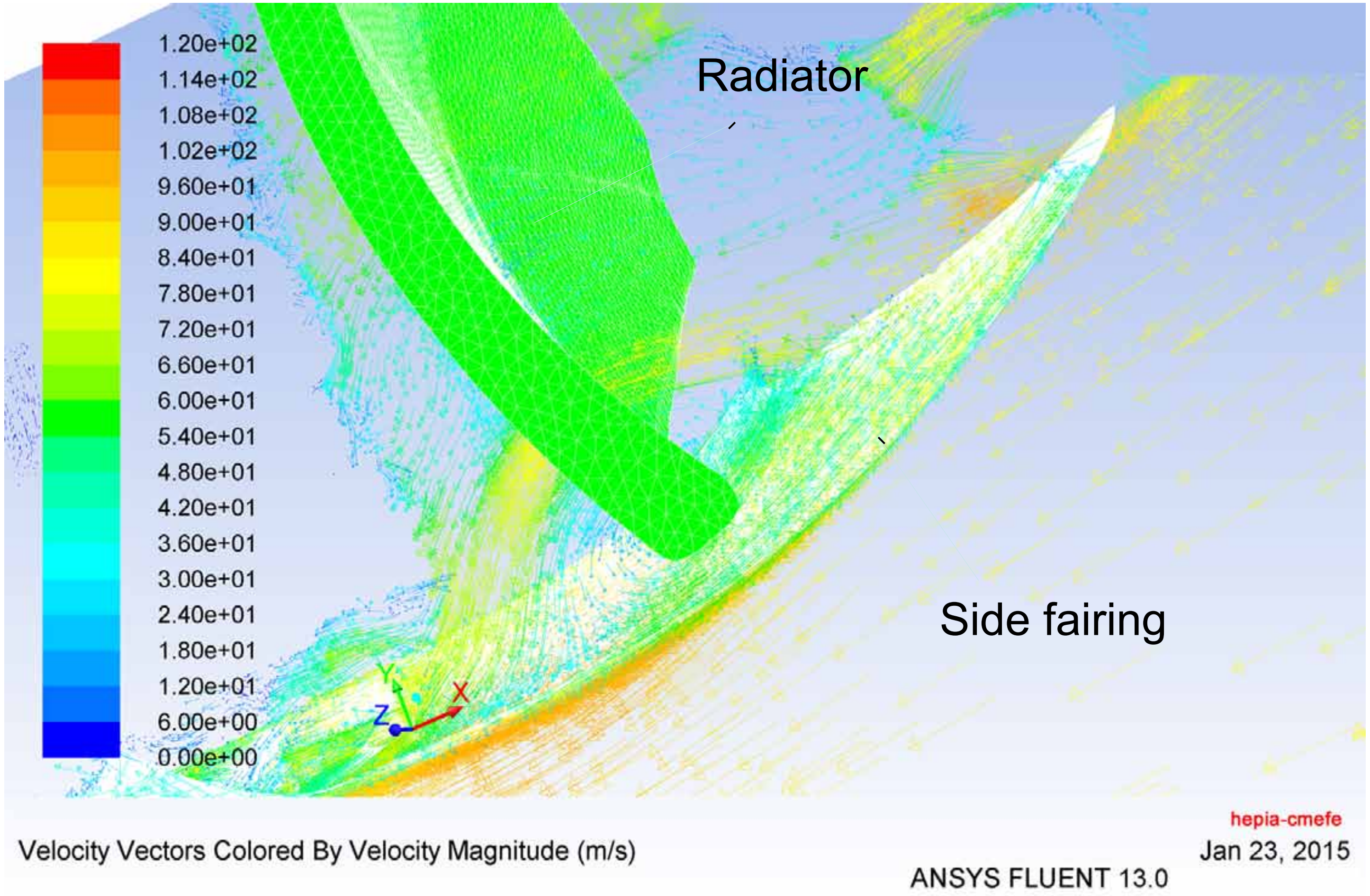


CFD SIMULATIONS



CFD SIMULATIONS

Example : Understanding of side fairings and radiator interactions
New design of the fairings and radiator.



FINAL RESULTS

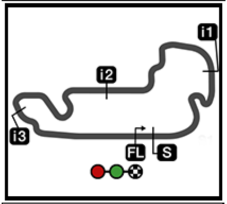
		SCx values
Moto2 Kalex Aegerter 2015 (with our work)		
CFD simulations	:	0.230
Wind tunnel full scale (corrected for aspect ratio)	:	0.250
Moto2 Kalex Aegerter 2015 (original)	:	0.290

- Gain on the aerodynamic drag of about 20% (original position and material)
- Selection of the best pilot position, seat design (thicknesses)
- Suit design (back) and helmet choice. Interaction between these two elements.
- Better design of several bike parts

RESULTS

- In the top speed of all moto2 riders during the full 2015 championship
- 7 speed records in 2015

anapolis Motor Speedw



4170 m.

Results and timing service provided by TISSOT

Moto2

RED BULL INDIANAPOLIS GRAND PRIX

After the Race

Event Best Maximum Speed

33

	Rider	*Nation*	*Team*	*Motorcycle*	*Km/h*	
12	**Thomas LUTHI**	**SWI**	Derendinger Racing Interwetten	KALEX	**290.0**	Race
77	**Dominique AEGERTER**	**SWI**	Technomag Racing Interwetten	KALEX	**289.3**	Free Practice Nr. 1
25	**Azlan SHAH**	**MAL**	IDEMITSU Honda Team Asia	KALEX	**288.7**	Race
11	**Sandro CORTESE**	**GER**	Dynavolt Intact GP	KALEX	**287.6**	Free Practice Nr. 3
73	**Alex MARQUEZ**	**SPA**	EG 0,0 Marc VDS	KALEX	**286.9**	Race
21	**Franco MORBIDELLI**	**ITA**	Italtrans Racing Team	KALEX	**286.8**	Race
1	**Tito RABAT**	**SPA**	EG 0,0 Marc VDS	KALEX	**286.8**	Race
39	**Luis SALOM**	**SPA**	Paginas Amarillas HP 40	KALEX	**286.3**	Qualifying
40	**Alex RINS**	**SPA**	Paginas Amarillas HP 40	KALEX	**286.0**	Race
36	**Mika KALLIO**	**FIN**	Italtrans Racing Team	KALEX	**285.9**	Race
97	**Xavier VIERGE**	**SPA**	Tech 3	TECH 3	**285.9**	Race

RESULTS

Illustration of the top speed gain achieved : Mugello 2015

Tito Rabat (1) not able to pass Dominique Aegerter (77) instead of speed gain obtained by aspiration.

CONCLUSIONS

- Between 1984, when hepia-cmefe write one of his first CFD code, and today, CFD technics appears in our works an extremely powerful tool.
- For all these years hepia-cmefe applied CFD in a great variety of projects in conjunction with experimental technics.
- When the benefit of CFD is well understood and not over / under evaluated, very efficient methodologies can be defined and used.
- The major risk when using CFD technics is the definition of the calculation domain. Where shall I put its boundaries ? Do I know the conditions to be imposed at the boundaries (sometime complex) ?

→ CFD simulation gives understanding and leads to new ideas.

This is a fantastic tool !!!

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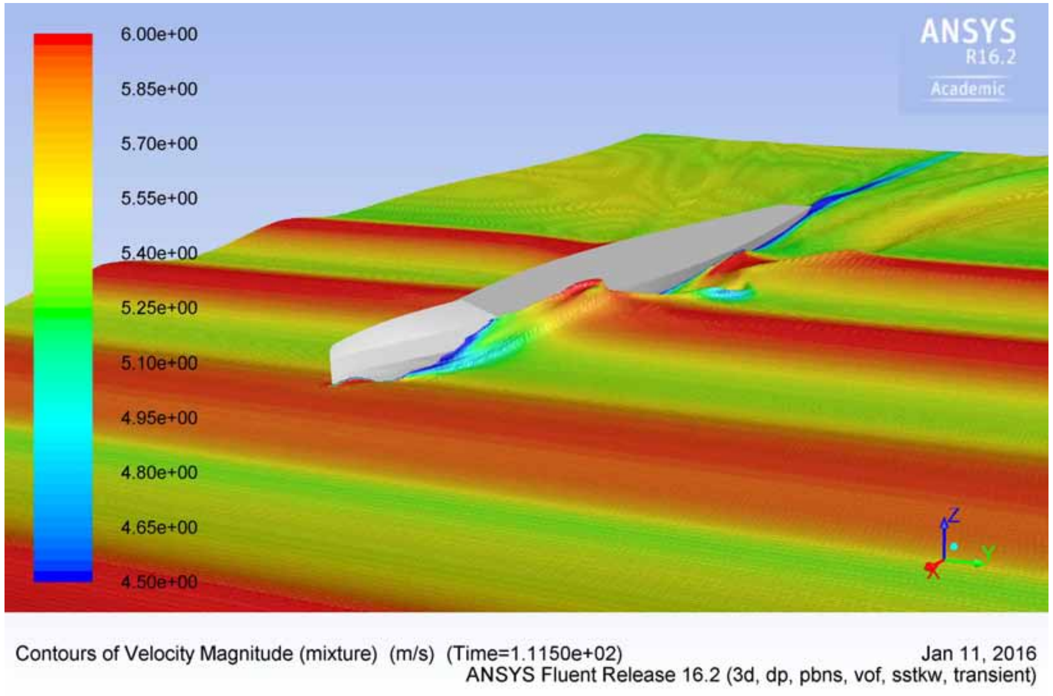
THANKS, QUESTIONS?



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