Università degli Studi di Roma Tor Vergata
Corso di Laurea e Dipartimento di Ingegneria Meccanica

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The evaluation of aerodynamic drag of go-karts by means of coast down test and CFD analysis

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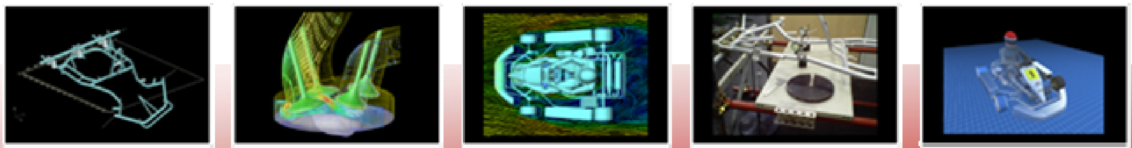

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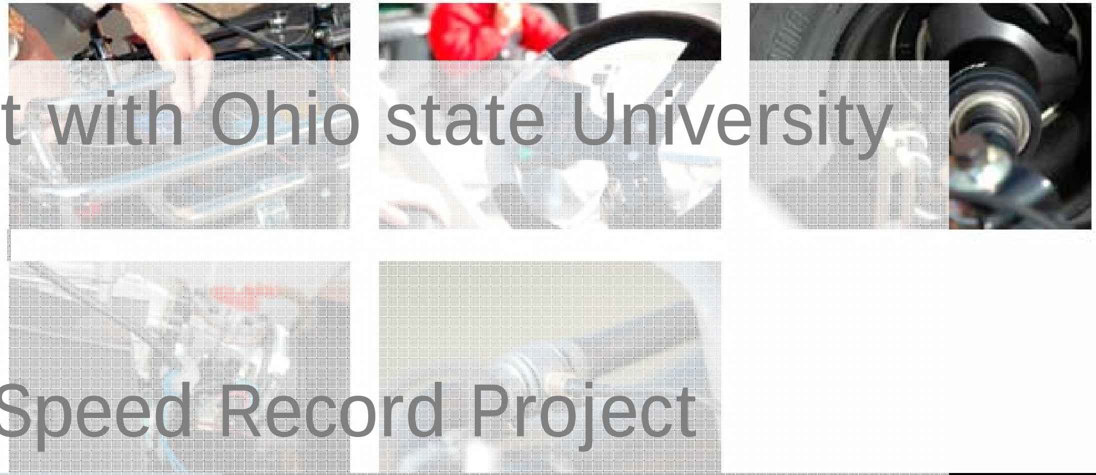
TVK Research Group

- The Tor Vergata Karting (TVK) Research Group was born in 2002.
- Active in the Motorsports field, from competition go-karts to Formulas.
- Development of multi-disciplinary simulation tools, ranging from structural mechanics and fluid dynamics to vehicle dynamics and innovative materials.
- Two spin-off companies are going to born
  - Engineering software tools for the design and optimization of competition go-karts (www.tvk-project.com)
  - Fluid-structure interaction and shape optimization tools to be integrated in the most used CFD software.

Land Speed Record



- Buckeye Bullet with Ohio state University
  - Suspensions
  - Chassis
- Go kart Land Speed Record Project
  - Drag evaluation (CFD, coast down test)
  - Mission simulation, sensitivity analysis
  - Bodywork optimisation (CFD, wind tunnel testing)

Goals of this study

- Aerodynamic Drag calculation by means of CFD analysis
- Evaluation of vehicle losses (Drag and Rolling) by means of coast down test
- Land speed record vehicle mission simulation
- Sensitivity analysis to drive LSR vehicle design and optimisation

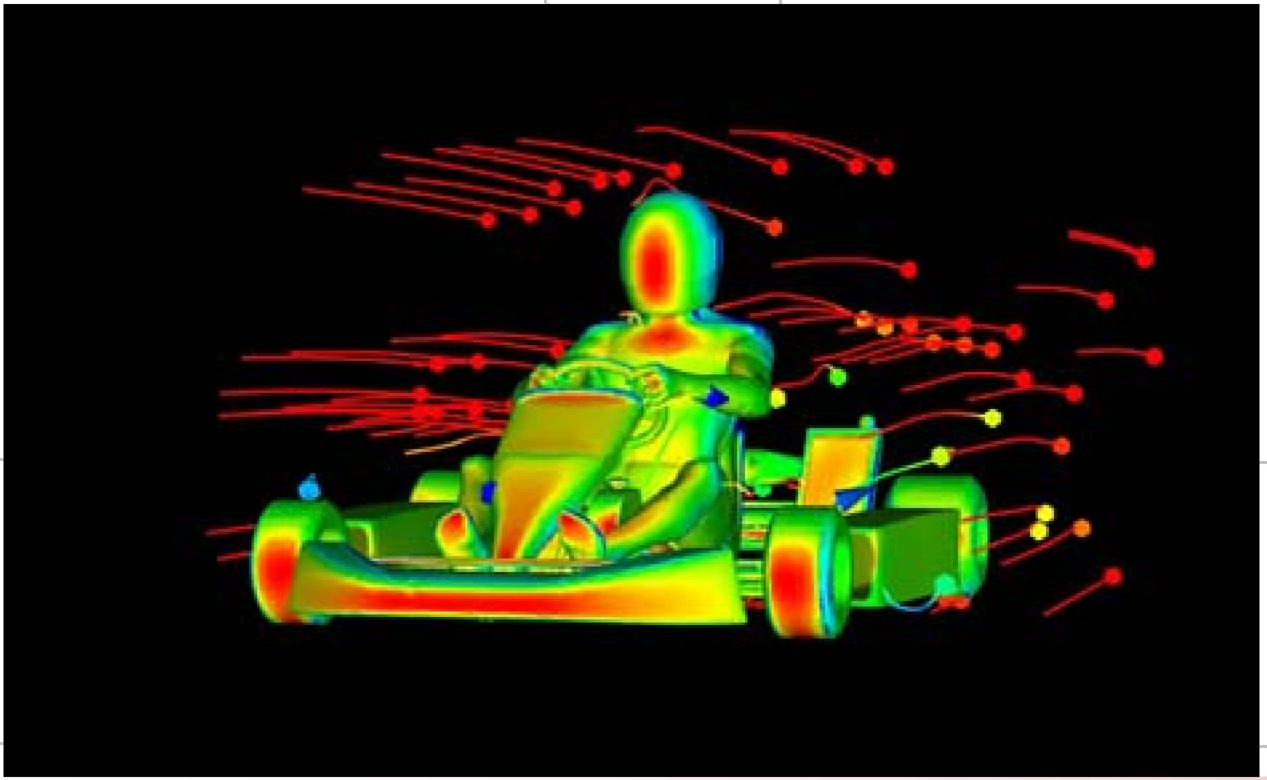
CFD Analysis

- Geometric model TVK 2003
- Full detailed CFD model in Fluent
  - Virtual wind tunnel
  - Reference speed 90 km/hr
  - Ground and wheels speed
- Drag forces analysis
  - Resultant
  - Distribution on vehicle parts

Geometric model

CFD model

- Pressure acting on wetted surfaces
- Stream lines of flow field



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CFD results: drag forces and down forces

- Forces on components
- Total lift: 30N
- Total drag: 173N
- CX calculation

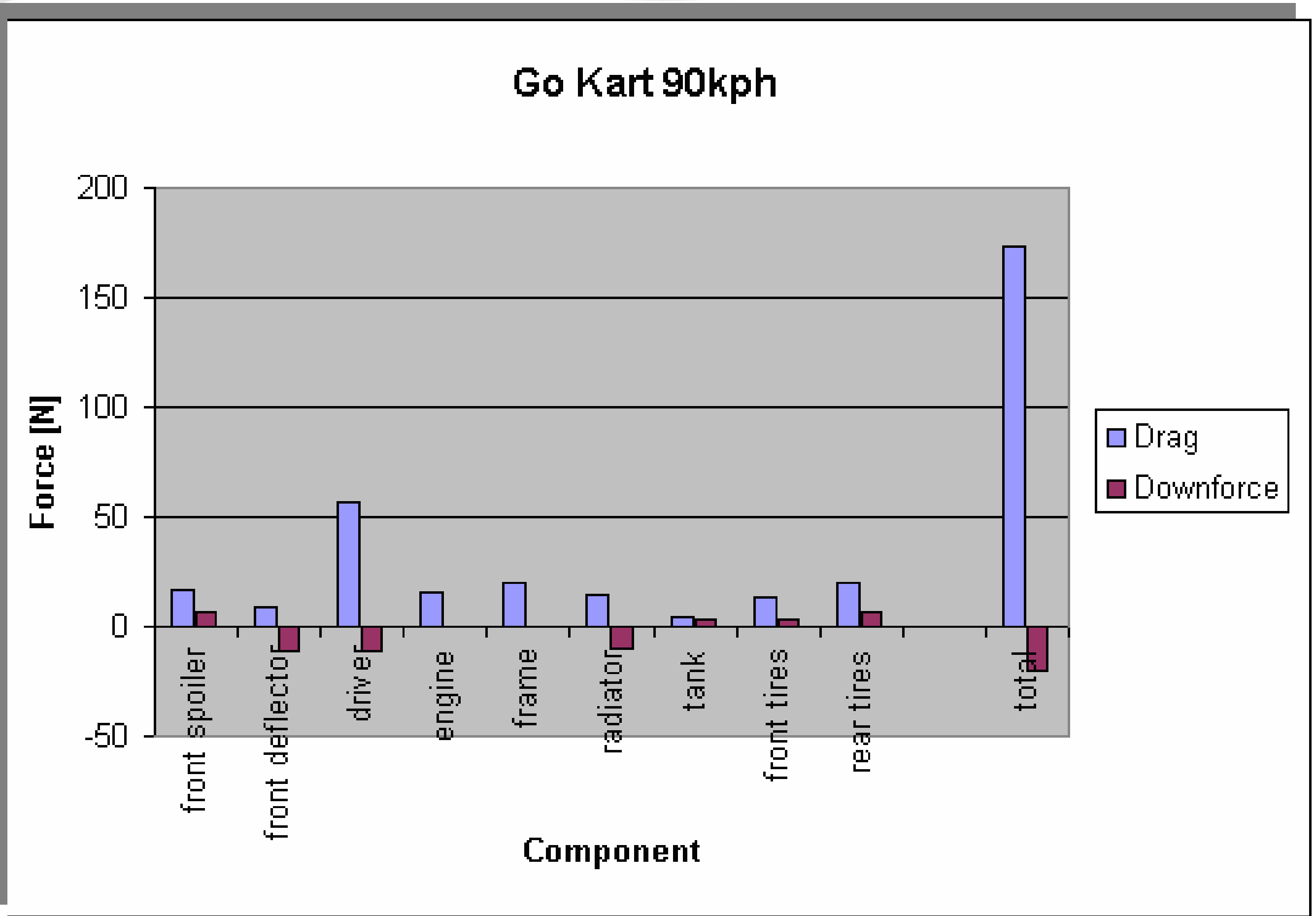
$$F_{drag}(v) = \frac{1}{2}\rho v^2 C_x A_{front}$$

$$A_{front} = 0.57484\, m^2$$

$$\rho = 1.2 \frac{kg}{m^3}$$

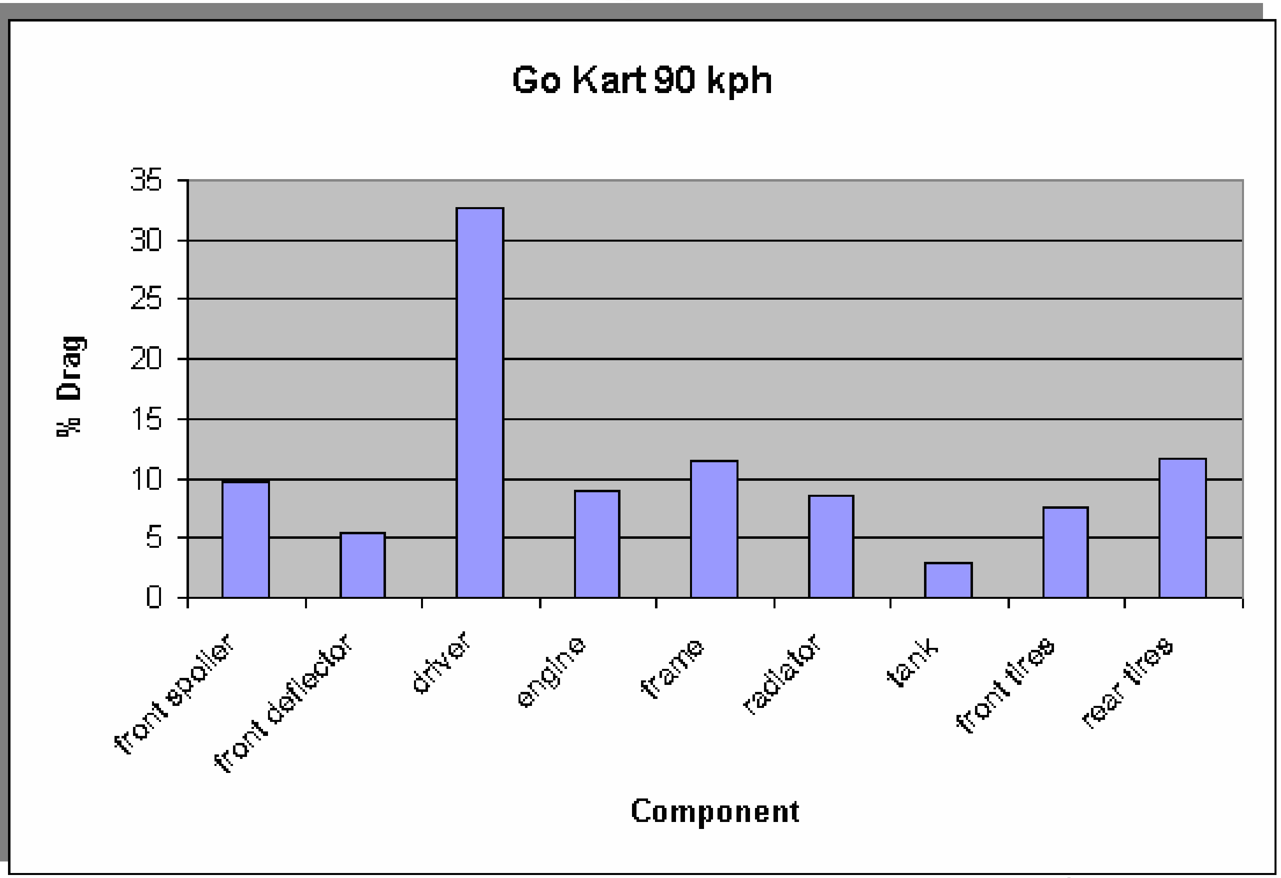
$$v = 90 \frac{km}{hr}$$

$$C_x = 0.78$$

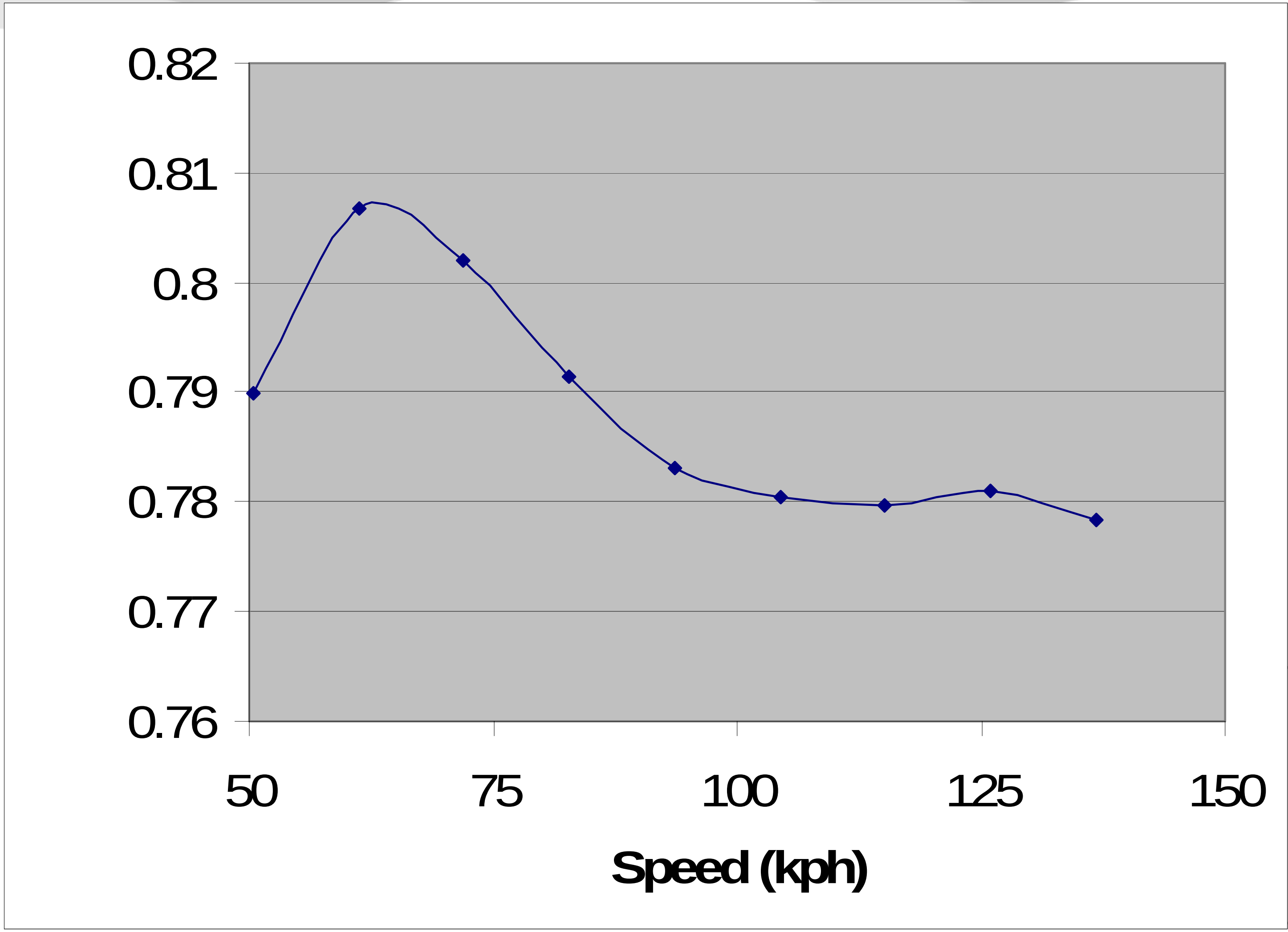


CFD result: drag distribution

- Contribution of components to global drag
- 33% driver
- 20% wheels
- 15% front spoiler and deflector
- 10% radiator



CFD results: CX vs speed



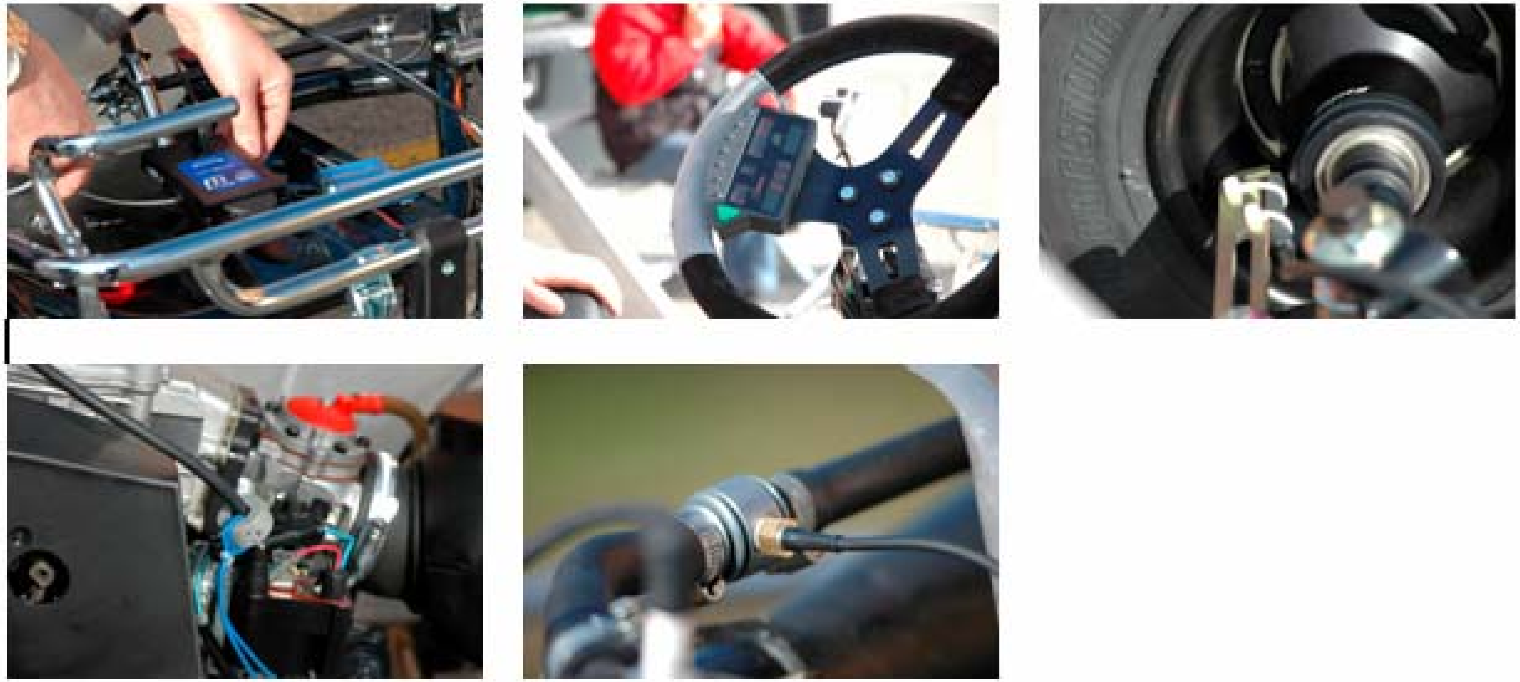
Experimental measurement of losses…

- Go kart: CRG 100 Black Star
- Engine: Maxter 100 2T
- Circuit: ISAM Anagni
- Driver: Gabbiani Jr.
- Data logger: PI Delta Clubman Kart Kit
- Technical support: Racing Team CIK, PI Research

...on track.

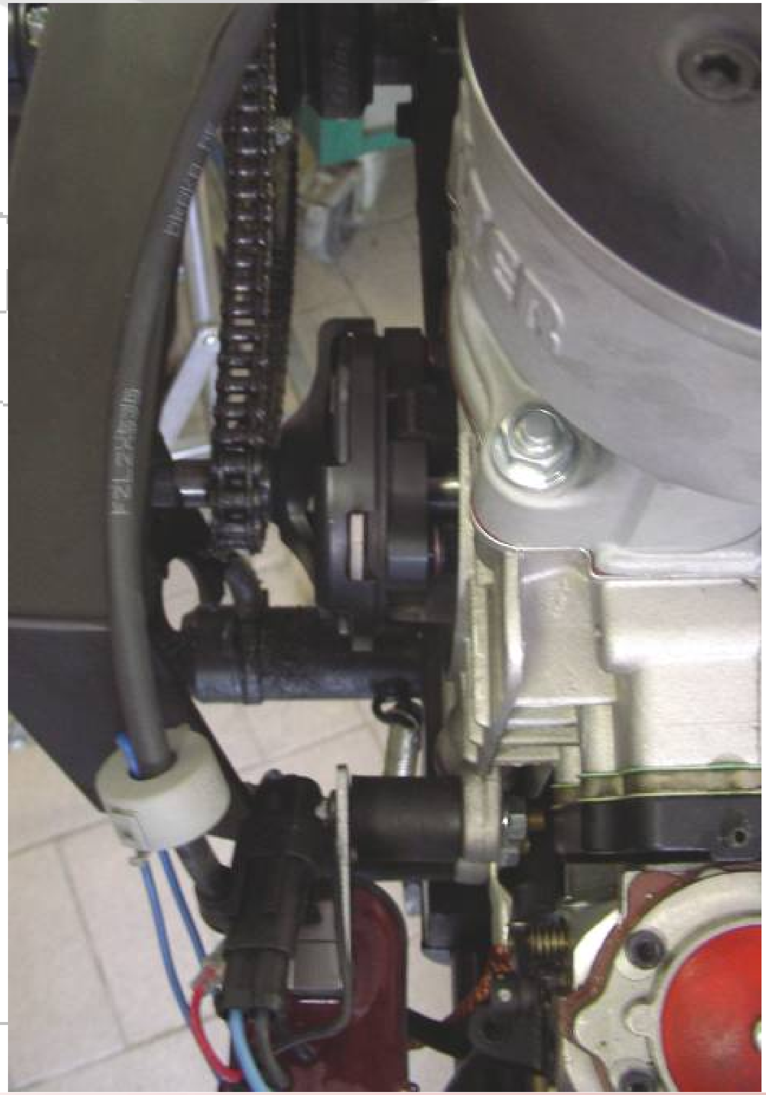
Acquisition system details

- Data logger PI Delta Clubman, dashboard PI X-Kart, speed sensor mounted on the front wheel
- RPM sensor coolant temperature sensor.



Acquisition system details

- Centrifugal clutch
  - Avoids rear axle locking at high speed in the event of engine failure
  - Allows to disconnect the engine while vehicle is running for the execution of coast down test



Measurement procedure for the evaluation of losses and engine thrust

- Deceleration data allow losses parameters to be identified.
- Test is performed disconnecting the engine at high speed along the straight.
- Acceleration data analysis allows actual thrust at the wheel to be estimated; torque curve can be derived introducing mechanical efficiency of the transmission.
- Test is performed accelerating the vehicle on the straight until maximum speed is achieved.

Data analysis theoretical model

- Vehicle equation of motion in longitudinal direction
- Thrust is related to dynamic torque delivered by the engine through the transmission ratio and efficiency
- Rolling losses and aerodynamic drag losses are accounted
- A model with stabilized constant CX is assumed (applicable for investigated speed range as confirmed by CFD analysis)

$$F_{.tot}(v) = Ma$$

$$F_{.tot}(v) = F_{thrust}(v) - F_{drag}(v) - F_{roll}(v)$$

$$F_{thrust}(v) = T\left(\frac{v}{2\pi R_{rot} Z_{tot}}\right)\frac{1}{R_{rot} Z_{tot}}\eta_t$$

$$F_{roll}(v) = Mg\left(f_0 + f_1 v\right)$$

$$F_{drag}(v) = \frac{1}{2}\rho v^2 C_x A_{front}$$

Free deceleration

- Observed acceleration and losses are a second order polynomial of speed
- Polynomial coefficients are related to unknown vehicle losses model parameters
- A regression algorithm allows to estimate unknown coefficients

$$\begin{cases} -Ma = Mg\left(f_0 + f_1 v\right) + \frac{1}{2}\rho v^2 C_x A_{front} \\ -Ma = av^2 + bv + c \end{cases}$$

$$\begin{cases} \frac{1}{2}\rho C_x A_{front} = a \\ Mgf_1 = b \\ Mgf_0 = c \end{cases}$$

Acceleration

- Identified coefficients for losses are introduced in the model
- Complete equation is imposed considering observed values of speed and acceleration
- The only unknown is the thrust
- Torque curve is computed

$$F_{.tot}(v) = Ma$$

$$F_{.tot}(v) = F_{thrust}(v) - F_{drag}(v) - F_{roll}(v)$$

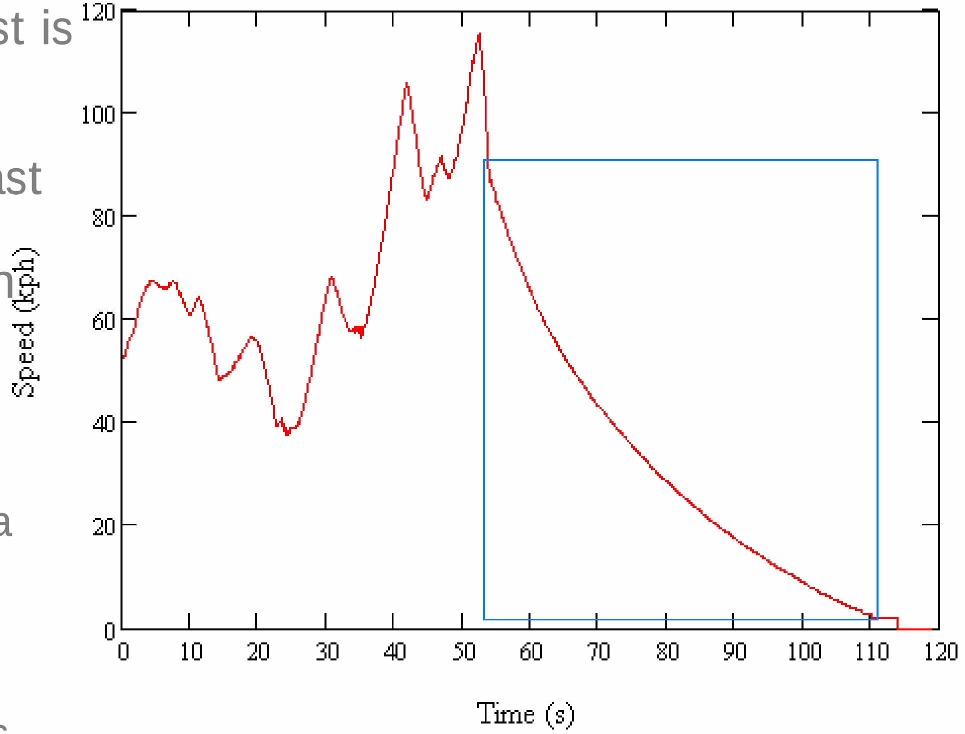
$$F_{thrust}(v) = T\left(\frac{v}{2\pi R_{rot} Z_{tot}}\right)\frac{1}{R_{rot} Z_{tot}}\eta_t$$

$$F_{roll}(v) = Mg\left(f_0 + f_1 v\right)$$

$$F_{drag}(v) = \frac{1}{2}\rho v^2 C_x A_{front}$$

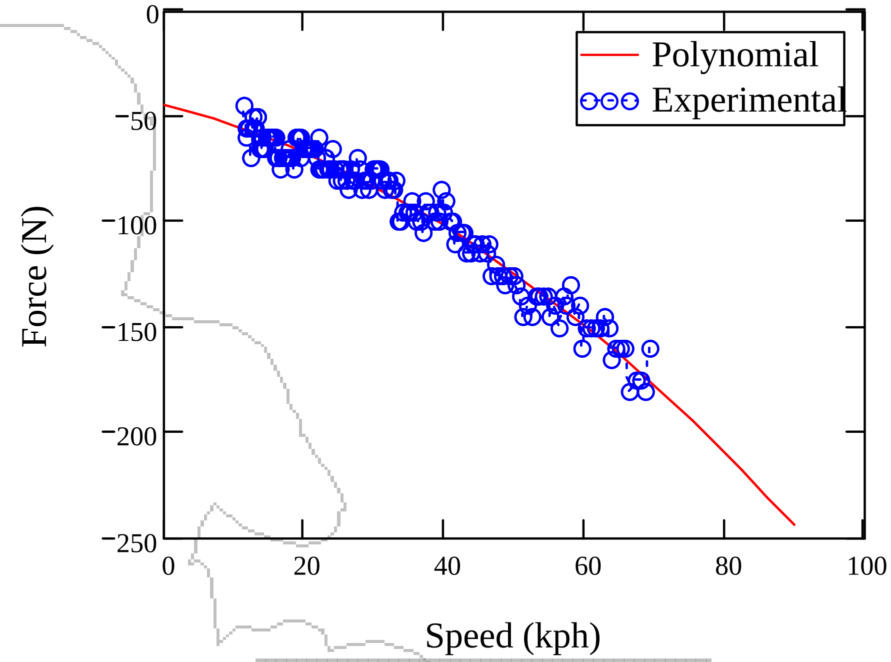
Results: deceleration

- At each lap a deceleration test is performed
- The portion of speed vs time curve recorded related to coast down is extracted
- Raw data are filtered (median smoothing)
- Step 1
  - Acceleration is computed by means of numerical differentiation of filtered data
  - Polynomial regression
- Step 2
  - Results of Step 1 are used as guess values
  - Least squares identification algorithm (integral formulation)



Results for reference vehicle set-up

- Comparison between experimental data and identified model

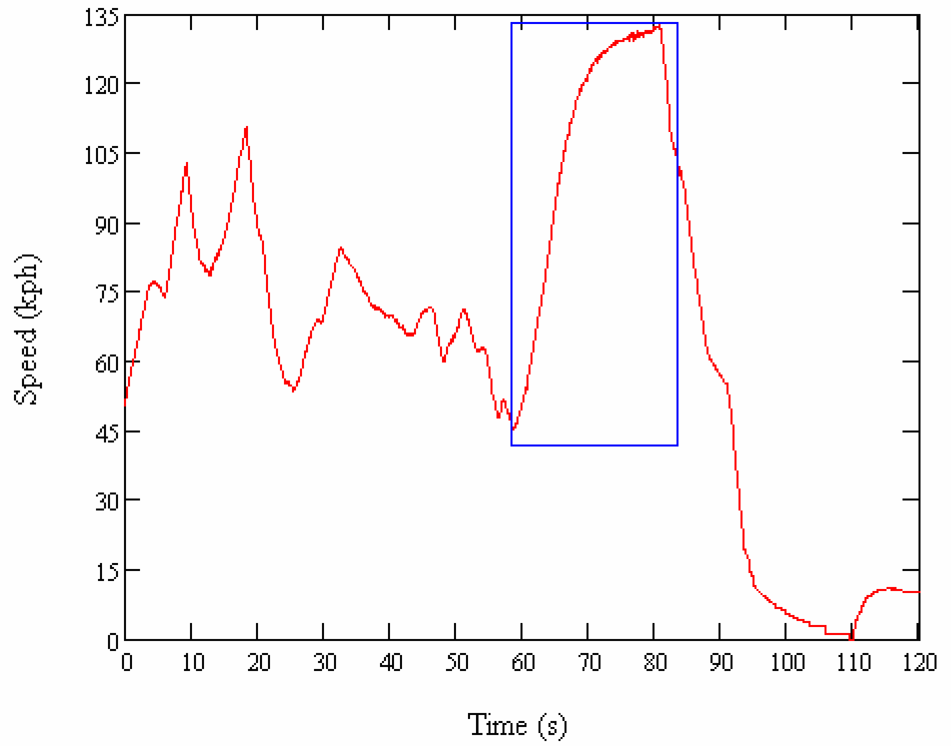


- Numerical values of loss model

$$\begin{cases} C_x = 0.899 \\ f_1 = -5.114 \cdot 10^{-4} \\ f_0 = 0.027 \end{cases}$$

Results: acceleration

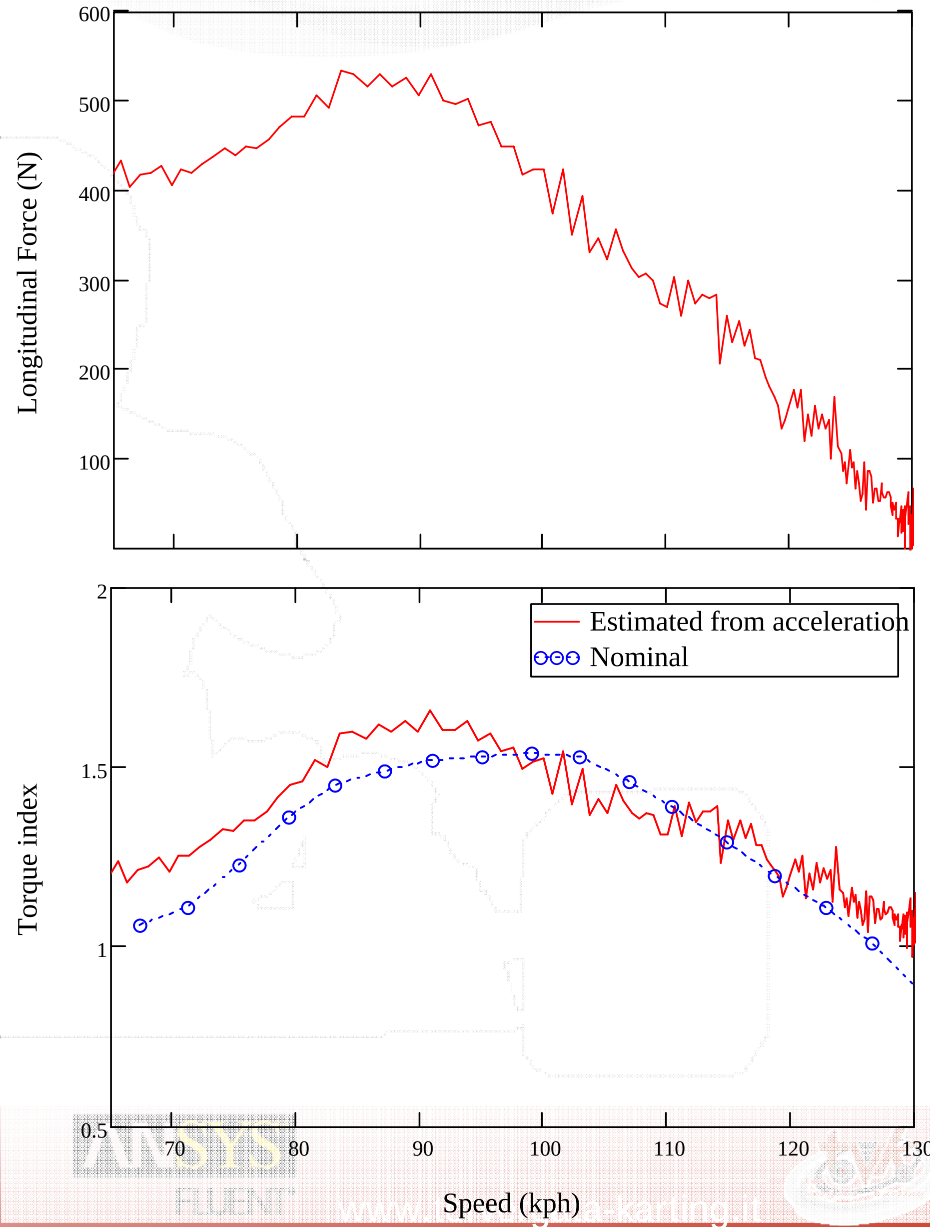
- At each lap an acceleration test is performed
- The portion of speed vs time curve recorded related to acceleration test is extracted
- Numerical differentiation of filtered data
- Thrust calculation
- Torque calculation



Thrust and torque curve

- Resultant of longitudinal force obtained from the acceleration curve

- Comparison between estimated torque curve and nominal torque curve provided by Maxter



Sensitivity analysis

- Mathematical model can be used to simulate the mission of LSR to estimate:
  - Sensitivity of top speed to model parameters
  - Acceleration time and space required to reach top speed
  - Planning of vehicle improvements toward a new record (current record is 185 km/hr for category investigated in this study)

Top speed calculation

- Theoretical top speed is calculated from equilibrium between engine max power and power loss

$$P_{\max}\eta_t = \left(Mg\left(f_0 + f_1 v\right) + \frac{1}{2}\rho v^2 C_x A_{front} \right) v$$

- Transmission ratio for top speed is obtained imposing that at top speed the engine runs at maximum power RPM

$$Z_{V\max} = \frac{RPM_{P\max} 2\pi R_{rot}}{v_{\max}}$$

Sensitivity analysis results

- Variation (± 40%) of each parameter (step 20%)
- Effect (%) on vehicle top speed

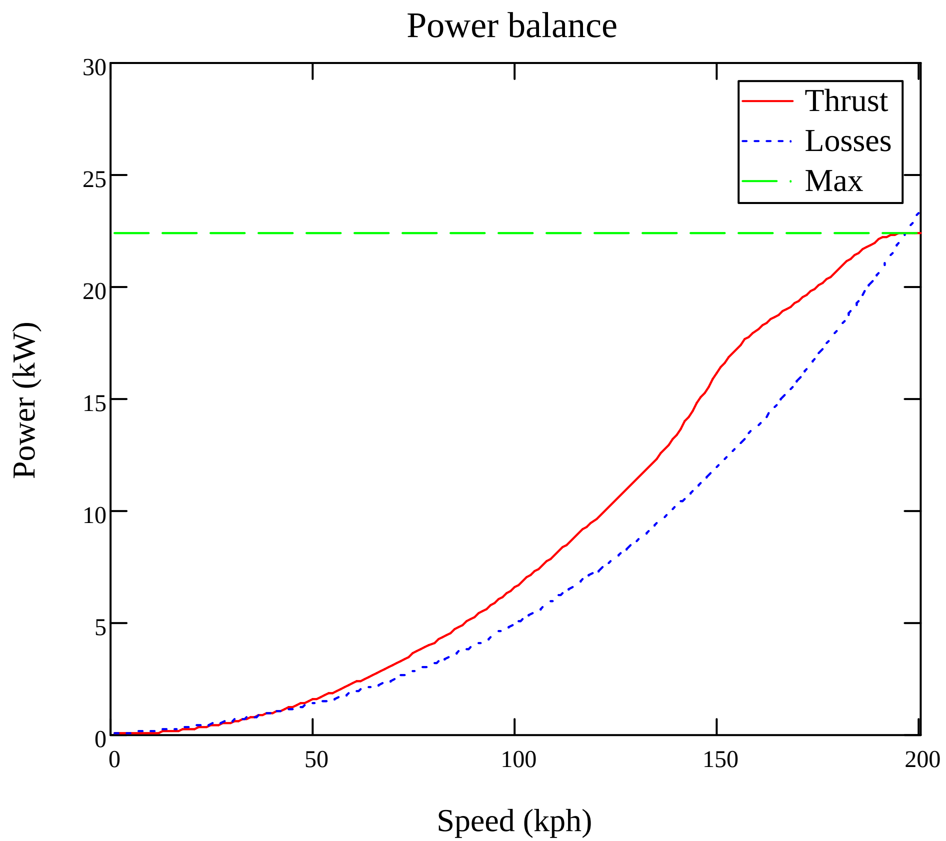
	-40%	-20%	20%	40%
Cx * Cross section	18.9	7.8	-5.9	-10.7
f0	-1.27	0.6	-0.6	-1.27
f1	-0.92	-0.46	0.46	0.93
Power	-16.3	-7.4	6.5	12.3
Weight	0.3	0.17	-0.17	-0.35

Feasible solution

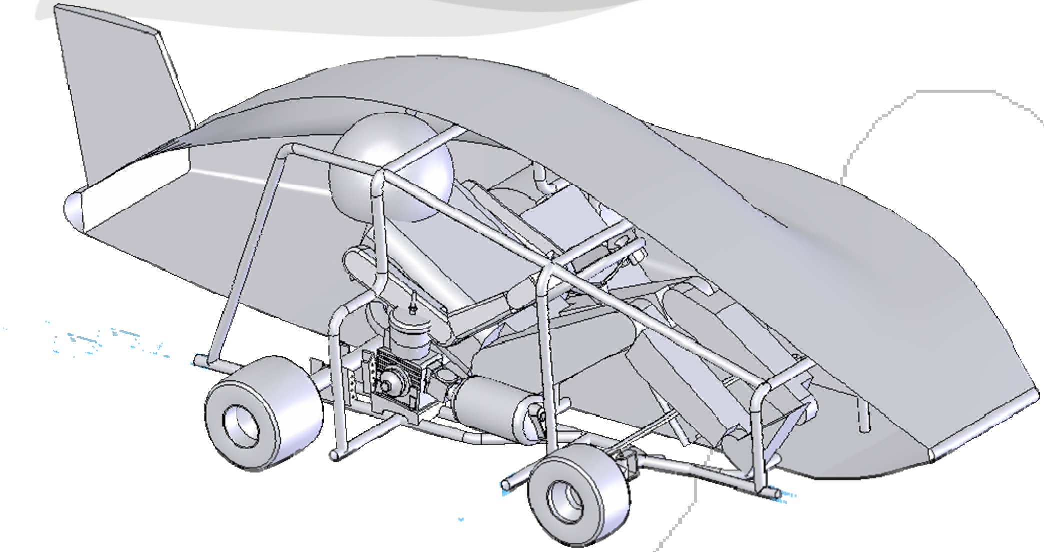
- Acting on the parameters that mainly influence top speed
  - Reduction of drag acting on bodywork
  - Increasing max power tuning the engine

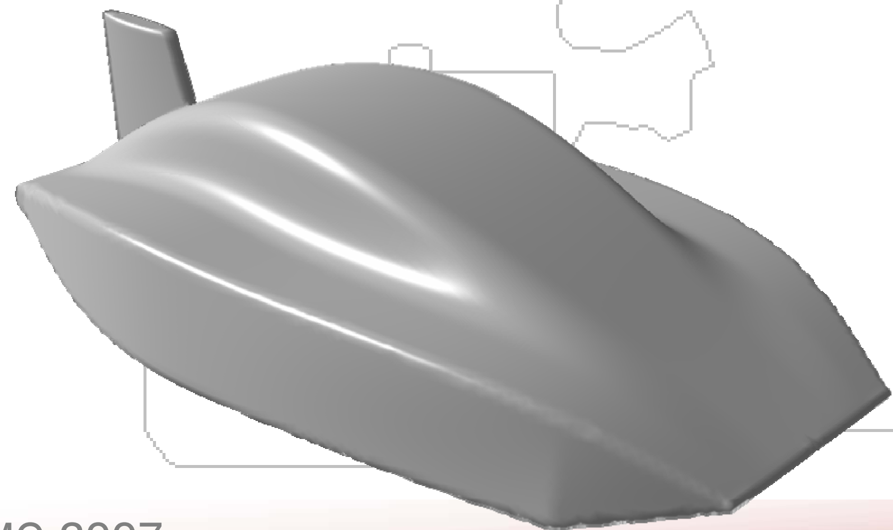
$$v_{max}(0.8, 26 \cdot hp) = 132.616 \frac{km}{hr}$$

$$v_{max}(0.2, 30 \cdot hp) = 196.61 \frac{km}{hr}$$



Feasible solution details





- Optimised driver position
- Roll bar and safety belts
- Streamlined bodywork for reduced drag
- Stabilizer fin
- Super kart high speed wheels
- CFD optimisation for CX reduction (currently 0.2 that could further be reduced)

Conclusions

- CFD analysis allows to perform a quantitative prediction of aerodynamic drag (Cx=0.78)
- The proposed experimental test method allows to evaluate loss model parameters (Cx=0.899) and actual engine thrust
- Different estimation can be related to the different set-up (different vehicle shape, different driver heights)
- CFD analysis allows to study in detail how drag is produced and how is distributed on vehicle components
- Mission simulation allows to optimise the project and to plan the event
- Proposed tools are currently in use to optimise the vehicle (bodywork, engine tuning, tyres)

Top Kart Speed Project is supported by:

- Ansys Fluent
- AVL
- PI Research
- Racing Team CIK
- ISAM proving ground
- CRG go-kart
- MAXTER engines

ANSYS FLUENT

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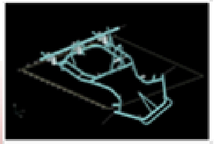
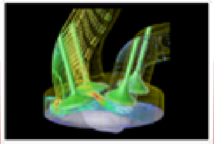
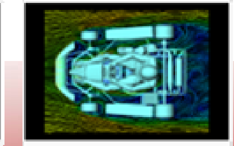
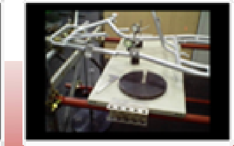
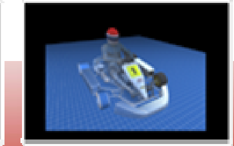

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