Report of Student Formula Project

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Aerospace Engineering,
Tohoku University
Contents

1. Background
2. Objective
3. Description of Our Car: TF13
4. Results
5. Details of Static Events
6. Points of Improvement in Technical Inspection
7. Summary
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A student design competition

- Organizer: Society of Automotive Engineering
- Sponsor: Toyota, Nissan, Honda ...
- The number of teams: 78 (EV: 8)

We design, build and test a car on our own

Not only performance, but marketing, planning, design, production and cost aspects are judged.
Outline of Events

Events (Points)

- **Static**: Cost (100)
  - Presentation (75)
  - Design (150)

- **Dynamic**: Acceleration (75)
  - Skidpad (50)
  - Autocross (150)
  - Endurance (300)
  - Fuel Economy (100)

http://blog.livedoor.jp/jsaeformula/

http://www.daido-news.jp/
We get support from Boeing to buy main components of EV

<table>
<thead>
<tr>
<th>Part</th>
<th>Unit Price(Yen)</th>
<th>Number</th>
<th>Price(Yen)</th>
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<tbody>
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<td>Steel Plate</td>
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<td>Brake Pedal</td>
<td>58,000</td>
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<td>58,000</td>
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<tr>
<td>Brake Caliper</td>
<td>2,000</td>
<td>4</td>
<td>8,000</td>
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<tr>
<td>Brake Rotor</td>
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<td>4</td>
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<td>Damper</td>
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<tr>
<td>Spring</td>
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<td>4</td>
<td>16,000</td>
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<td>Bolt</td>
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<td>4</td>
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<td>Bearing</td>
<td>1,000</td>
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<td>36,000</td>
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<tr>
<td>Slick Tire</td>
<td>35,000</td>
<td>4</td>
<td>140,000</td>
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<tr>
<td>Wheel for Slick Tire</td>
<td>38,000</td>
<td>4</td>
<td>152,000</td>
</tr>
<tr>
<td>Rain Tire</td>
<td>35,000</td>
<td>4</td>
<td>140,000</td>
</tr>
<tr>
<td>Wheel for Rain Tire</td>
<td>38,000</td>
<td>4</td>
<td>152,000</td>
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<tr>
<td>Sprocket Adjuster</td>
<td>1,000</td>
<td>1</td>
<td>1,000</td>
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<tr>
<td>Sprocket</td>
<td>6,000</td>
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<td>12,000</td>
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<tr>
<td>Chain</td>
<td>10,000</td>
<td>2</td>
<td>20,000</td>
</tr>
<tr>
<td>Limited-Slip Differential</td>
<td>8,000</td>
<td>1</td>
<td>8,000</td>
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<tr>
<td>Housing</td>
<td>500</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>Support Link</td>
<td>500</td>
<td>1</td>
<td>500</td>
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<tr>
<td>Shaft</td>
<td>18,000</td>
<td>2</td>
<td>36,000</td>
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<tr>
<td>Electric Motor</td>
<td>130,000</td>
<td>1</td>
<td>130,000</td>
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<tr>
<td>Total Price</td>
<td></td>
<td></td>
<td>1,500,000</td>
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</table>
Contents

1. Background
2. Objective
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Objective

To win the EV total performance award at Student Formula Japan in 2013, we plan, design and build an EV car

http://www.jsae.or.jp/formula/jp/
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Direction of Design

Merits of EV
- The battery can be placed near the center
  - Good weight balance and mass concentration will be achieved
- The electric motor does not need big space
  - The driving position can be put close to C.G.

Rival Car: The frame designed for CV is used
- Cannot take full advantage of electrification

By designing a car tailored for the electric powertrain, excellent dynamic performance will be gained

http://www.sist.ac.jp/club/f-sae/
Concept: **Human-Centric**
- Short wheelbase (1530 mm)
- Short overhang (600 mm)
- 50:50 front/rear weight balance
- Mass concentration
- The driving position close to C.G.

**Quick and Neutral Handling**

*Good performance in the autocross and endurance event will be expected*
Comparison with Rival Car

TF13

<table>
<thead>
<tr>
<th>Specification (Not Firm)</th>
<th></th>
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<tbody>
<tr>
<td>Frame</td>
<td>Steel</td>
</tr>
<tr>
<td>Body-work</td>
<td>Steel</td>
</tr>
<tr>
<td>Overall Length</td>
<td>2300 mm</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>1530 mm</td>
</tr>
<tr>
<td>Track</td>
<td>Front: 1175 mm, Rear: 1175 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1050 mm</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>37.5 mm</td>
</tr>
<tr>
<td>Wheel</td>
<td>10 inch</td>
</tr>
<tr>
<td>Weight</td>
<td>270 kg</td>
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<tr>
<td>Weight Dist.</td>
<td>50:50</td>
</tr>
<tr>
<td>Rated Power</td>
<td>12 kW</td>
</tr>
<tr>
<td>Max. Power</td>
<td>30 kW</td>
</tr>
<tr>
<td>Battery</td>
<td>Li-ion, 5.9 kWh, 96 V</td>
</tr>
<tr>
<td>Suspension</td>
<td>Front: Pushrod, Rear: Pushrod</td>
</tr>
</tbody>
</table>

The Rival Car (2011)

http://www.kumikomi.net/

<table>
<thead>
<tr>
<th>Specification (2012)</th>
<th></th>
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<tbody>
<tr>
<td>Frame</td>
<td>Steel</td>
</tr>
<tr>
<td>Body-work</td>
<td>CFRP</td>
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<tr>
<td>Overall Length</td>
<td>2815 mm</td>
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<tr>
<td>Wheelbase</td>
<td>1600 mm</td>
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<tr>
<td>Track</td>
<td>Front: 1150 mm, Rear: 1150 mm</td>
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<tr>
<td>Height</td>
<td>1074 mm</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>36 mm</td>
</tr>
<tr>
<td>Wheel</td>
<td>13 inch</td>
</tr>
<tr>
<td>Weight</td>
<td>270 kg</td>
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<td>Weight Dist.</td>
<td>30:70</td>
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<tr>
<td>Rated Power</td>
<td>15 kW</td>
</tr>
<tr>
<td>Max. Power</td>
<td>37 kW</td>
</tr>
<tr>
<td>Battery</td>
<td>Li-ion, 380 V</td>
</tr>
<tr>
<td>Suspension</td>
<td>Front: Pushrod, Rear: Pullrod</td>
</tr>
</tbody>
</table>

C.G.
Photo of completed car
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# Results

Overall Standing (EV): 4\textsuperscript{th} / 8 teams  
(All): 69\textsuperscript{th} / 78 teams

<table>
<thead>
<tr>
<th>Event</th>
<th>Points</th>
<th>Time</th>
<th>Ranking (EV)</th>
<th>Ranking (All)</th>
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</thead>
<tbody>
<tr>
<td>Cost</td>
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<td>1\textsuperscript{st}</td>
<td>61\textsuperscript{st}</td>
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<td>Presentation</td>
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<td>1\textsuperscript{st}</td>
<td>13\textsuperscript{th}</td>
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<tr>
<td>Design</td>
<td>25.00</td>
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<td>3\textsuperscript{rd}</td>
<td>67\textsuperscript{th}</td>
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<tr>
<td>Acceleration</td>
<td>0 (DNA)</td>
<td>0.00 (DNF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skid-Pad</td>
<td>0 (DNA)</td>
<td>0.00 (DNF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autocross</td>
<td>0 (DNA)</td>
<td>0.00 (DNF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>0 (DNA)</td>
<td>0.00 (DNF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>0 (DNA)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Design Event

25 points / 150, 3rd / 8 (EV), 67th / 78 (All)

x Accuracy of design report
x Preparation for Q&A

Early confirmation of design is important
Cost Event

4.12 points / 100, 1st / 8 (EV), 61st / 78 (All)

- Real case scenario based on measurement
- Accuracy of cost report
- Addendum reflecting changes or corrections
- Consensus for real case scenario
- Drawing of manufacturing processes
- Preparation for Q&A

Early confirmation of design is important
Presentation Event

52.5 points / 75, 1st / 8 (EV), 13rd / 78 (All)

✓ Marketing making use of merits of EV
x Misunderstanding of rule
x Not enough rehearsal
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Electrical

① Isolation in high voltage system
② Wiring
③ Motherboard
④ Illumination of brake lamp

② and ③ are due to lack of sufficient test

Improvement Approaches
✓ Tagging wire for easy identification of the cause of failure
✓ The motherboard in a dust-free / protection case
✓ Operation test in the early stage
① Center nut for tire hub

Double nut is prohibited
Lock nut and split pin should be used
② Clearance around front tire
   Tire and frame surrounding battery are close
③ Height of Side Impact Structure
Result of ensuring suspension stroke
④ “I” marks and torque control at bolt and nut
Mechanical

⑤ Knuckle arm and frame are in contact
Stopper at rack and pinion is required
Mechanical

⑥ Height of steering wheel

Failure in arrangement of steering shaft
Screws without securing strength are used in suspension and steering system.

Strengthened screws should be used.
Mechanical

⑧ Interference of seat and belt
Mechanical

⑨ Protection for steering shaft
⑩ Fixation of Roll Bar Pad
Mechanical

⑪ Driver’s foot space
Gearbox and driven sprocket are misaligned
Mechanical

13. Rigidity for brake pedal
   Direction of return spring
Mechanical

⑭ Interference of brake caliper and wheel
Mechanical

15 Steering gear ratio
Failure in arrangement of rack and pinion
Investigation of Cause

③ Height of Side Impact Structure
   ...Suspension
⑤ Knuckle arm and frame
   ...Frame
⑪ Driver’s foot space
   ...Steering
⑮ Steering gear ratio
   ...Steering

Determination delay of specs of suspension and steering system caused these problems

Improvement Approaches

✓ Reuse main components for early production and improvement
✓ Arrangement of components prior to designing frame structure
✓ Design having additional margin for flexibility
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Our objective was to win the EV total performance award at Student Formula Japan in 2013.

We could not pass the technical inspection and fail to proceed to the dynamic events.

We challenge again next year and take the following improvement approaches to pass the technical inspection.
Summary

For Electrical Inspection
- Tagging wire for easy identification of the cause of failure
- The motherboard in a dust-free / protection case
- Operation test in the early stage

For Mechanical Inspection
- Reuse main components for early production and improvement
- Arrangement of components prior to designing frame structure
- Design having additional margin for flexibility
TF14
Thank you for your attention.
Frame

Human-Centric
- 50:50 front/rear weight balance
- Mass concentration
- Ergonomic driving position

Easy to Manufacture
- Steel pipe space frame
- Reduction of the number of welded point

Extensibility
- Simple constitution
Suspension

- Human-Centric
  - Conventional geometry

- Easy to Manufacture
  - Simple constitution

- Extensibility
  - Wide Adjustable Range
Drivetrain

Human-Centric
  ▸ Abolishment of the gearbox

Easy to Manufacture
  ▸ Single-reduction system

Extensibility
  ▸ Chain drive
Motor

Human-Centric

- PMS Axial Gap Motor (30 kW / 5000 rpm)
Battery

Design based on performance curves
## 9. Outline of Events

<table>
<thead>
<tr>
<th>Static Events</th>
<th><strong>Cost</strong></th>
<th>The validity/competitiveness of cost calculation are examined. (100P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Design</strong></td>
<td>Appropriateness, the reformation, the processability, and the repair, etc. of the design are examined. (150P)</td>
</tr>
<tr>
<td></td>
<td><strong>Presentation</strong></td>
<td>The presentation technology for the manufacturing sales is examined. (75P)</td>
</tr>
<tr>
<td>Dynamic Events</td>
<td><strong>Acceleration</strong></td>
<td>The acceleration performance from 0 to 75m. (75P)</td>
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<tr>
<td></td>
<td><strong>Skid-pad</strong></td>
<td>The vehicle’s cornering performance is evaluated in steady state turns over a figure-of-eight course. (50P)</td>
</tr>
<tr>
<td></td>
<td><strong>Autocross</strong></td>
<td>Vehicles are driven over an approximately 800 m course comprised of a combination of straights, turns, and slaloms. (150P)</td>
</tr>
<tr>
<td></td>
<td><strong>Endurance</strong></td>
<td>Vehicles are driven over an approximately 20 km course comprised of a combination of straights, turns, and slaloms. (300P)</td>
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<tr>
<td></td>
<td><strong>Fuel economy</strong></td>
<td>Fuel economy is evaluated in terms of the amount of fuel consumed in the endurance. (100P)</td>
</tr>
</tbody>
</table>
10. Work Environment

- **Funding**
  - $28,000 (from club budget, Univ. and Co.)
  - *We don’t have enough money yet*

- **Design**
  - 2D CAD: Jw_cad, 3D CAD: SolidWorks2010

- **Manufacturing**
  - Tools, Welder (manual, semiautomatic), etc.
  - *We don’t have the surface plate*
  - *Made a small surface plate by steel scrap*

We need to use these extremely limited resources much effectively
11. Team Objective

The Ultimate Formula Student Car

- Overwhelming Dynamic Performance
- Universal Stability and Controllability
- Extremely High Energy Efficiency

Gasoline cars cannot achieve them at the same time

Electric Motor, Battery and Electronic Control..., only EVs can achieve them

Tohoku University will make the ultimate formula student car
12. Team Plan

TF13 (2013) Objective: **Realize of entry and victory**  
Approach: Basic of Car Design

TF14 (2014) Objective: **Challenge to TF13’s limits**  
Approach: Improvement Based on Data and Simulation  
Traction Control

TF15 (2015) Objective: **Exceed the gasoline cars**  
Approach: Twin Front Motor  
Front-Rear Wheel Control

TF16 (2016) Objective: **The ultimate formula student car**  
Approach: Twin Rear Motor  
All Wheel Independent Control
目的：電費性能向上によるバッテリー重量の削減
目標：電費：0.1kWh/km（2012年大会優勝校：0.13kWh/km）
バッテリー重量：50kg減
方策：① 軽量化，② モータ制御

2013年：ベンチマーク車両開発，各種データ取得，問題発見
2014年：解決方法模索，コンピュータ・シミュレーション，実験
2015年：走行試験，実戦投入
2013年：ベンチマーク車両開発，各種データ取得，問題発見

開発：工作性を最重視，挙動を把握しやすく，操作に鋭敏な設計
①ボディ…溶接点数が少ない構造（ジグなし誤差最大5mm）
低慣性モーメント，良好な重量配分（50：50），
高剛性（1G旋回時トーイン0.001°未満）を狙った設計
入手しやすいGFRPを用いたカウル
②足回り…製作・調整しやすい単純な構造・ジオメトリ
③駆動系…ロバストで調整しやすいチェーンドライブ
軽量かつ運転しやすい変速なし自作ギアボックス
エネルギー密度の高いリチウムイオンバッテリ

研究：サス・ブレーキ・ステア・モータ＆バッテリセッティング，
電流・電圧値，加速度，アクセル・ブレーキ開度，舵角等の
走行データの取得，破損箇所の調査，滑り検出方法の模索
TF14

2014年：解決方法模索，コンピュータ・シミュレーション，実験

開発：マイナーチェンジ（TF13をベースとした部分的改良）
①ボディ…ウェットカーボンカウルによる軽量化→-5kg
②足回り…部品形状最適化による軽量化
③駆動系…モータ・減速方式改善による軽量化（アルミ＆カーボンハイブリッド減速機など）→-4kg
駆動力制御による消費電力の低減

研究：ドライカーボンパネルの成形，金属との接着，スチールパイプとのハイブリッドフレームの実験
フレーム・カウル形状変更による空気抵抗低減効果の検証（CFD）
走行データの取得，破損箇所の調査
TF15

2015年：走行試験，実戦投入
開発 ：フルモデルチェンジ（TF13の問題を考慮した抜本的改革）
①ボディ…スチールパイプ＆ドライカーボンパネル
ハイブリッドフレームによる軽量化→-3kg
空気抵抗低減カウルによる消費電力低減
②足回り…10インチMgホイールによる軽量化→-5kg
③駆動系…自作コントローラによる軽量化
回生方式の再検討（キャパシタ, フライホイール等）

研究：走行データの取得，破損箇所の調査，
エコ走行を補助するAndroidアプリの開発，
更なる電費向上方法の策定（4輪独立モータによる回生効率の
向上，サス・ブレーキ・ステア制御による消費電力の低減等），
太陽光発電パドックによる創エネ等
The autocross and endurance course mainly consist of less than 10 m radius turns, so the ability to turn in a small radius is needed.

->Trend: **Short Wheelbase** (1525 mm ~)

Because of the engine behind the driver, the driving position is apart from the C.G.

x Difficult to understand the vehicle behavior

To improve maneuverability, departure from the internal combustion engine and the alternative is needed.
14. Objective

To win the total performance award, we design and build the formula student car tailored for the electric powertrain and realize “Jinba-Ittai”*

* Japanese word for unity of horse and rider