Using TRIZ in Project-Based-Learning Assisted by CAE and Manufacturing Experiences

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Abstract

Kanagawa Institute of Technology has drastically changed its teaching method to project based learning (PBL) from a conventional system. Conventional teaching system teaches subjects separately. It begins with teaching basics only to freshmen and finally tries to synthesize students' knowledge in theses. However, students tend to lose momentum of learning desire under this conventional system. To wake freshmen's interest in engineering subjects and to develop their skill of applying knowledge to real problems are the major objectives of this PBL. In this report, two examples of invention by students in PBL will be presented. One is an engine intake system design that solves trade-offs between maximizing engine performances and minimizing space the system occupies. The other is a front suspension system that enables a newly developed walking aid to over-ride high gaps with small thrust force while giving it stability and shock absorbing function. In both cases, students' skill of using computer aided engineering (CAE) software and their manufacturing experience has an important role. It was found that PBL is a good environment to teach TRIZ, and CAE and manufacturing experiences help students to learn it.

1. INTRODUCTION

Engineering schools must teach engineering. Engineering includes invention. Therefore, engineering schools must teach skills of invention. An old proverb says "Necessity is the mother of invention." However, is there any necessity in college level subjects? If not, students at engineering school cannot bear children without mother. Conventional curriculum at Kanagawa Institute of Technology (KAIT) where the author teaches has been adopting conventional curriculum in which students have been taught basic engineering subjects step by step separately. The students had to learn how to organize the knowledge they acquired in usual course works only when they encountered real problems in industry after graduation because most of the theses they engaged were focused in analyses rather than synthesis.

To solve this problem, the KAIT adopted project based learning (PBL) method. One of the projects this paper describes is Formula SAE racing car development project.(1) In this project, students tackle with such activities as, product concept generation, conceptual design, and detail design, performance prediction by CAE, prototype manufacturing, testing and then competing in racing tracks. To win the race, they need to create new and good units. Time, cost and human power are all scarce. They need to run computer simulation and to manufacture a number of parts by themselves. These circumstances are proved to be fertile soil for invention teaching.

Another project this study deals with is development of a walking aid for outdoors. This project aims to change the concept of walking aids from just a rehabilitation tool on flat hospital floors to a vehicle can lead handicapped users to such places as post office, convenient stores, etc. To do this job, the walking aid the students tried to develop had to have such performances as getting over gaps, increased anti-turnover stability, turning in a small circle, and shock insulation. However, there was no such product in market yet.

In this paper what found to be useful for teaching invention with TRIZ method are described in case study manner.

2. CASE STUDY No.1: Engine Intake System

2.1 Project description

2.1.1 What is the "FormulaSAE"?

The Formula SAE competition is for SAE student members to conceive, design, fabricate, and compete with small formula-style racing cars. (Fig.1) The restrictions on the car frame and engine are limited so that the knowledge, creativity, and imagination of the students are challenged. The cars are built with a team effort over a period of about one year and are taken to the annual competition for judging and comparison with approximately 140 other vehicles from colleges and universities throughout the world. The end result is a great experience for young engineers in a meaningful engineering project as well as the opportunity of working in a dedicated team effort

Fig.1 Formula SAE racing car

2.1.2 How the participants are evaluated?
Students compete to get as much scores as possible in two events, i.e. static and dynamic. The full mark is 1,000 points. The static event consists of concept presentation, design judge and cost analysis report. The dynamic event consists of acceleration, turning on a skid pad, time trial on an auto-cross course, and endurance and fuel economy run.

2.2 Restrictions on the engine design

According to the Formula SAE rule such restrictions are placed on the engine design.
1) Piston displacement must be less than 0.61 liters.
2) In order to limit the power capability from the engine, a single circular restrictor must be placed in the intake system between the throttle and the engine and all engine airflow must pass through the restrictor. The restrictor diameter is 20 mm.
3) The complete air intake system must lie within the surface defined by the top of the roll bar and the outside edge of the four tires. (Fig.2)

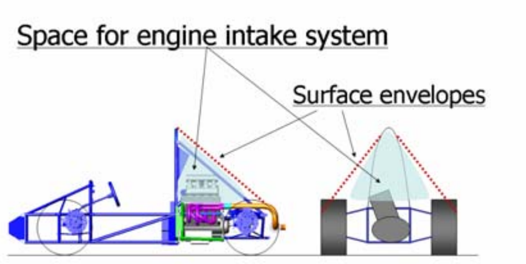


Fig.2 Space limitation for the intake system

In addition to these rules, the main parts of the engine are usually provided by automotive industry because they are too expensive and complicated to build by the students. This situation brings another restriction to the engine design.

2.3 Required engine performance

2.3.1 Lower speed range
The shape of the race track for auto-cross event and endurance run is changed annually, and its exact dimensions are never released to the participants even after the events. It is very winding with a number of hair-pin curves and slaloms. (Fig.3) This race track shape may give the engine different running conditions than it is used on roads. To investigate the speed range that should be used on the Formula SAE racing track most frequently, the students of KAIT walked along the track carrying a global positioning system (GPS) last year. Using the data collected by the GPS, they drew a simplified model track on a parking lot with typical hairpin corners, high speed corners and slaloms. (Fig.4) From the engine speed distribution logged from the engine control system (ECU), the high torque speed range was found to be from 8,000 to 10,000 rpm. (Fig.5) This is lower than that of the base engine performance by about 25 %.

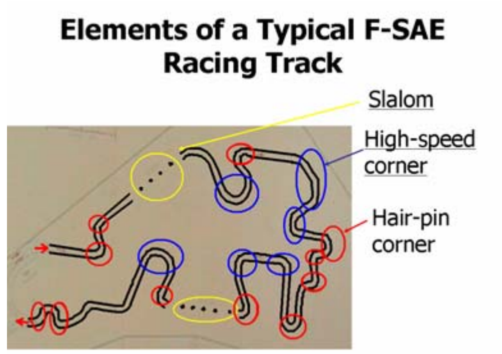


Fig.3 Typical Formula SAE racing track

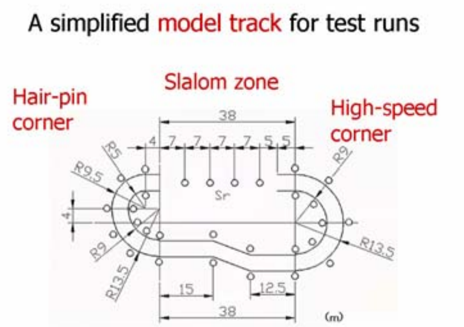


Fig.4 A simplified model track

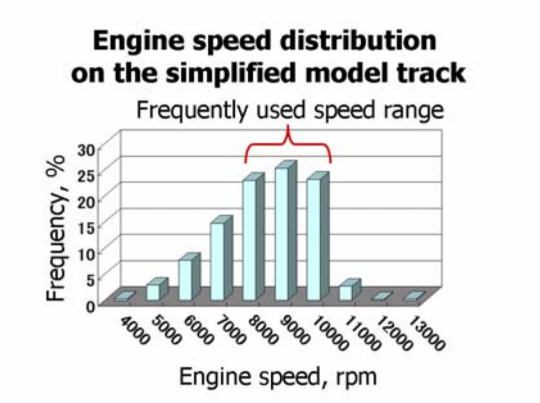


Fig.5 Frequently used engine speed range

2.3.2 Quick response

Because the drive on the race track is a chain of acceleration and deceleration, the engine needs to respond to the throttle valve quickly. Among several elements of delay in engine response, the delay in intake air flow is the main element. The air runs through the throttle valve has to fill the volume in the intake tube, collector and intake manifold. The system can be modeled as a first order system consisting of an orifice and a reservoir.

2.4 Design principle and embodiment design

2.4.1 Utilization of intake air inertia effect

At the onset of intake stroke of a cylinder, the air in the intake system has to be accelerated to reach full air flow rate in the middle of the stroke. At the end of the intake stroke, the air inside the intake system tends to keep flowing into the cylinder because of the inertia force of itself, and eventually charges the cylinder with dense air and fuel mixture. This mechanism is called as inertia effect. To use this effect, the intake tube must be in a proper length determined by resonant frequency of the air column inside the tube. (Fig.6)

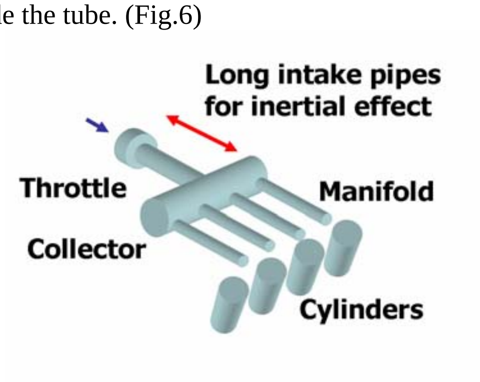


Fig.6 Intake system

The resonant frequency has to be tuned to the above mentioned engine speed range. If we take the mid point of the speed range, then the frequency f_r has to be,

$$f_r = \frac{9,000\,rpm}{60\,s} \times 2\ firings/stroke = 300\,Hz$$

To obtain this resonant frequency with air column vibration, the rough estimation of the intake tube length L [mm] is calculated as,

$$L = c/4f_r = 340/4\times 300 = 0.28[m]$$

where, c is the speed of sound. However, it is a hard to install this length tube within the space limitation as shown in Fig.2.

2.4.2 Collector volume optimization

To assure quick response, the collector volume should be small. By simplifying the intake air flow response to the throttle valve actuation, the pressure drop Δp from ambient air to the pressure in the collector is given by such expression as,

$$\Delta p = \Delta p(0)\exp\{-(kp_a/V)t\}$$

where, k, p_a, V are the intake tube flow resistance, ambient pressure and the collector volume. The time constant $T_c = V/kp_a$ is desired to be within a few cycle period of the engine. For engine speed of 6,000 rpm, T_c is somewhere around $20:30$ ms. Taking a typical value of k as $1\text{x}10^{-5}$ m^3/s, the volume should be,

$$V \le 0.003[m^3] = 3[l]$$

Another consideration on the collector volume optimization is to minimize the collector pressure fluctuation. This is for assuring uniform air flow distribution over all the cylinders and over time. The suitable range for this function, the collector volume is usually chosen as four times of engine piston displacement by experienced engineers.

Considering such conditions as the above, the collector volume was determined as,

$$V = 2.2[l]$$

2.4.2 Intake system performance simulation

Using a engine gas exchange process simulation software BOOST[(2)], the pressure fluctuations, engine output torque vs. engine speed, etc. were calculated. (Fig.7)

By giving such values of the intake tube length, L, and the collector volume, V, the intake system design was found to satisfy the objectives. At this stage, no detail shape is determined. Only a set of quasi-one-dimensional design parameters was determined. However, the student's ability of using CAE reduced the scope of design consideration and let him move quickly to embodiment design and invention.

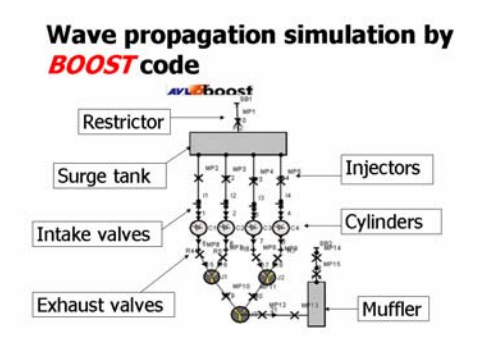


Fig.7 A model for simulating engine gas exchange

2.4.3 Embodiment design of intake system
<u>(A) Collector design</u>
The necessary functions are,

1) To minimize pressure drop
2) To give uniform air flow distribution over all cylinders.

The strategy to realize the functions are,

1) To slow down the air flow.
2) To avoid sharp corners along the flow passage.
3) To assure equal cross sectional area to the flow passage to each cylinder.
4) To give same shapes and bents to the flow passage to each cylinder.

The restriction coming from manufacturing capability is that casting was not possible for this case. This restriction is a heavy burden to the student as the shape that can be realized by sheet metal work is limited.
Considering the above mentioned conditions, possible arrangement is to build the collector in a kind of cylinder and to install the intake tube at an end plate.

(B) Intake tube design
The intake tube contains air flow restrictor with 20mm inner diameter at its inlet portion. The latter part of this tube need to act as a diffuser that recovers pressure. To do this function with minimum energy loss caused by turbulence, the student found the maximum divergence angle allowable is below 15^{o} from the results of computational fluid dynamics (CFD). (Fig.8) Another restriction on this tube design is that it must be straight to ensure inside wall smoothness.

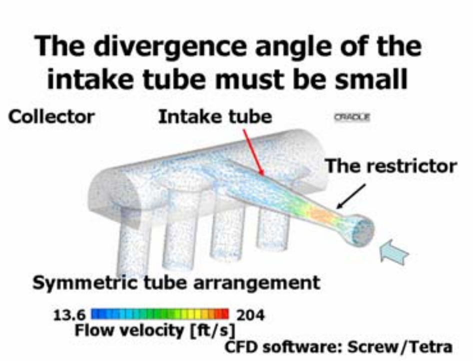


Fig.8 Flow velocity inside of the intake tube

2.5 Invention

2.5.1 Contradictions
A) The intake tube must be long and straight.
B) The collector must have enough volume.
C) The collector must give each cylinder equal air flow with minimum turbulence.
D) Each component must be made with simple tools.
E) Over all intake system must lie in a small space.

Translating these contradictions into TRIZ terminology, the combinations of the features to change and undesired result were obtained as Table1.

Table 1 Contradiction matrix in the intake design

Feature to change	Undesired result	principle
Length of non-moving objedt	Area of non-moving object	17, 7, 10, 40
	Volume of moving object	35, 8, 2, 14
	force	28, 10
	power	12, 8

2.5.2 Inventive principles induced
Among the multiple inventive principles given by TRIZ listed in the Table1, such principles as below lead to concrete design ideas.
#7 Nesting: An object passes through a cavity of another object. From this principle, an idea of inserting the intake tube deep into the collector was born.
#14 Spheroidality: Replace flat surface with curved surface. From this principle, an idea of making a baffle plate of the collector into a hemispherical wall to turn the airflow smoothly.
#17 Moving to a new dimension: Move an object in a plane to three dimensional space. This principle released the student from designing the air movement in a plane in the collector to three dimensional flow with radial and rotational movement.

2.5.3 Realization of the inventive principle

By synthesizing the inventive principle, the student draw a cross sectional view of the intake system. (Fig.9) The air flowing down from the restrictor is released at the end of the intake tube. Then, it expands, reduces its speed, and encounters the hemispherical end wall. The flow diverges three dimensionally and surrounds the intake tube. This first motion enables the air to stabilize and to minimize turbulence. The flow to each cylinder has almost same cross sectional area by the conical shape of the collector.

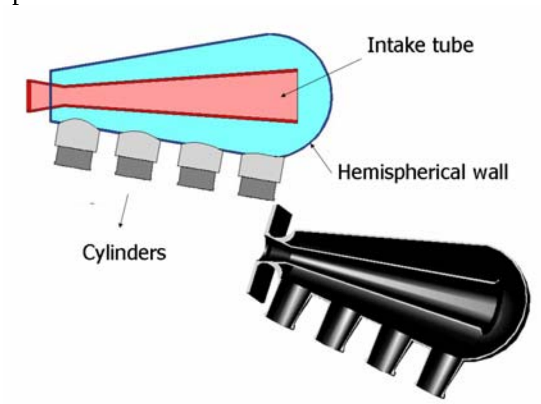


Fig.9 Cross-section of the invented intake system

An important aspect of this invention can be found in estimation of performance improvement using CAE. The inventor built a CFD model based on a three dimensional CAD model. The results of the CFD simulation were encouraging. (Fig.10) The streamlines were smooth for every cylinder intake stroke.

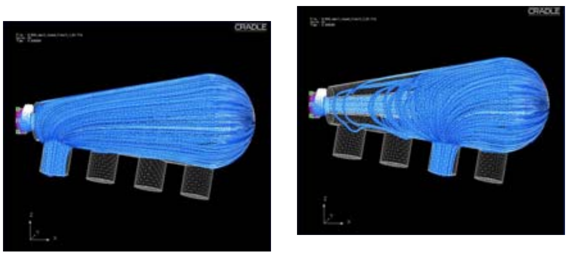


Fig.10 Calculated stream lines. Left: Cylinder no.1 intake stroke, Right: Cylinder no.3 intake stroke

The construction of the collector by sheet metal work only seemed to be hard. The student modified the drawing to make the spherical wall by machining with a lathe. By making this wall stiff and accurate, the other portion of the collector was able to be built with good accuracy and necessary flow performance was obtained. The student's experience in making automotive parts supported the realization of his invention. This was another key point.

3. CASE STUDY No.2: Walking aid for outdoors

3.1 Project description

To give more mobility to people with walking difficulties, a walking aid for outdoors was developed.[3] The use of this walking aid is supposed to go to a nearby post office, convenient stores, etc. to fill daily needs and to exercise. Walking aids for outdoor use must run over rough surface like motor vehicles, while giving small vibration and sure support to their users. The aids must turn in small space and stop in desired manner. One of the hardest problems in this project was to develop a front wheel and suspension system that can ride over gaps. The gap height to be ridden over is 50mm, which represents typical curbstone height.

3.2 Mechanics of gap over-ride

When the walking aid over-rides a gap, it needs a large thrust force. This thrust and the reaction force from the gap edge caused pitch down moment. (Fig.11) To assure enough stability margin, either L, the distance between the front wheel and the center of gravity, should be large or F, the thrust, should be small.

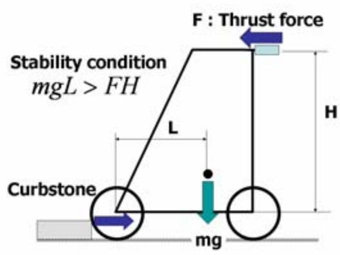


Fig.11 Static balance of pitch moments

To reduce the maximum thrust, the simplest design solution is to enlarge the front wheel diameter, and to reduce the slope of the front wheel center trace. (Fig.12) However, large size front wheel deprives the user of foot moving space. Therefore, this design cannot be a solution.

The large thrust caused not only pitch instability, but also gives uncomfortable shock to the user. (Fig.13 left) Some shock absorbing device is necessary n between the front wheel and the frame. However, normal spring may invite instability.

The waveform of the required thrust force is peaky and only lasts a fraction of second. (Fig.13 right)

To summarize the contradiction the student faced at the beginning of the design stage are,

Feature to change: Thrust force reduction.
Undesired result: Large diameter wheel, Instability.

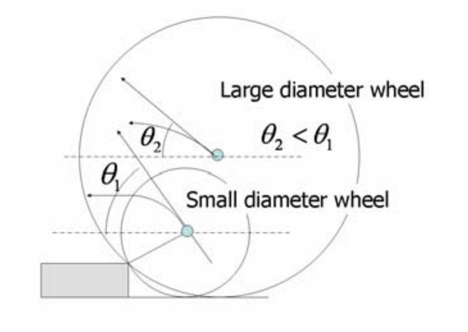
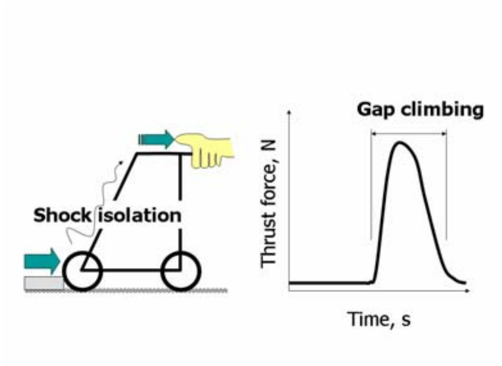


Fig.12 Large diameter wheel makes climbing slope gentler.



Fit.13 Requirement of shock isolation and the peaky waveform of the thrust force.

3.3 Invention principles

The TRIZ invention principles were not so obvious in this case. The student focused on such principles, though.

1) Segmentation: To divide a large wheel into a number of small wheels to form a large diameter envelope circle. (Fig. 14)
2) Asymmetry: Use only the front part of the said envelope circle.
3) Prior action: Store energy in spring beforehand and use it when the front wheel really climbs the gap. This makes the waveform of thrust flatter.

3.4 Realization of the inventive principle

3.4.1 Structure

The invented front wheel suspension system is shown in Fig.14. It has two wheels at the end of a V-shaped link. The link can swing around a pivot bearing suspended by a torsion spring with its end fixed on the frame. The leading wheel is smaller in diameter than the main wheel that carries load in normal conditions. The main wheel center is located to the rear side of the pivot so as to act as a caster.

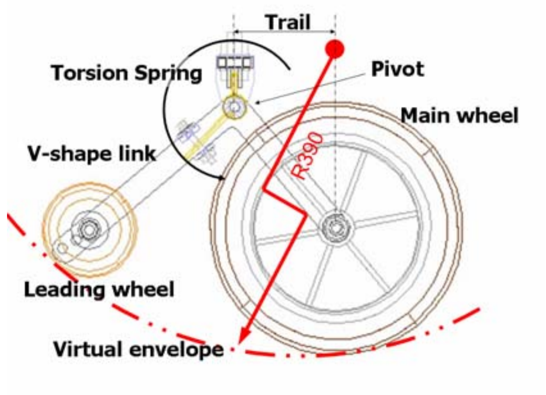


Fig.14 Invented front wheel system

3.4.2 How the front suspension is intended to work

When the main wheel hits the edge of a gap, the wheel remains on a ground for a while. The torsion spring and the pivot allow the V-shaped ling swing. Then, the leading wheel touches the upper surface of the gap. This timing is the onset of the gap climbing. Until this time, the torsion spring stores energy. Because the motion of the wheels swings around the pivot, the system behaves like a large diameter wheel. The leading wheel gives larger pitching stability by securing large distance from the center of gravity.

3.5 Testing the idea

3.5.1 Multi-body dynamics simulation

The idea drawn from TRIZ was conceived only qualitatively. The designer was able to imagine only static balance of forces. To understand whether the idea is really works, the student made a simulation model of multi-body dynamics (MBD). (Fig.15)

The result met his expectation. (Fig. 16) The trace of the pivot point movement during the gap climbing is much smoother than that of conventional rigid suspension system. This is another example that CAE experience helps invention.

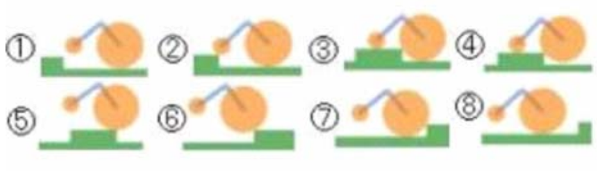


Fig.15 Multi-body dynnamics model for testing the idea of suspension

3.5.2 Prototyping and subjective evaluation

Though the thrust force or movement of the aid can be roughly calculated, final evaluation should be made by the users. The student built a prototype of the walking aid. Fig. 17 is one of the results of the quantitative evaluation. The thrust force during gap climbing is just below the threshold, i.e.128N withot power assist. The student found the spring constant affected the feel of the gap climbing. They tuned a few design parameters using the hardware to complete the invention.

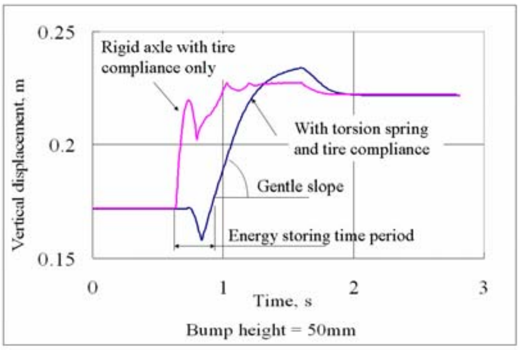


Fig.16 Calculated trace of the front suspension

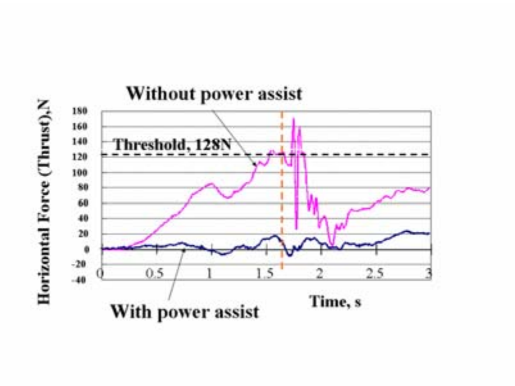


Fig.17 Measured thrust on a prototype

4. Conclusions

Through the two case studies, important lessons in teaching students invention were acquired. Students' skill of using computer aided engineering (CAE) software and their manufacturing experience has an important role in learning invention. It was also found that project based learning is a good environment to teach TRIZ.

5. Acknowledgements

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