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

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Objectives

- To search effective methods to teach invention to students.
- To improve project-based-learning curriculum by using TRIZ.

CASE STUDY No.1:
Engine Intake System

Design for Formula SAE
Racing Car Development
Student Competition

What is the "Formula SAE"?

- Purpose: Engineering education
- Organizer: *SAE*

(Society of Automotive Engineers)

- Venue: Michigan, U.S.A.
- Time: May, every year since 1989
- Participants: 140 Universities World wide
- Sponsor: Big3 and major Auto companies.

How the participants are evaluated?

- Full marks: 1,000 points.
- Static Event Competition; 350 points
  - Product concept presentation
  - Design judge (Technological aspect)
  - Cost analysis $\leq \$30,000 \approx 3,300,000 Yen$
- Dynamic Event Competition; 650 points
  - Standing start acceleration
  - Turning on a skid pad
  - Time trial on an auto-cross course
  - Endurance and fuel economy run

Position of this project in our education

- A regular subject at our Vehicle Engineering Department
- Project based learning
- Consists of lecture series, design reviews, laboratory works, fund raising, public relations, tours, etc.
- Students: Any student (from freshmen to seniors)

What the students can learn

- Skill of integrating fundamental knowledge in many disciplines.
- Grasp the idea of whole engineering process, i.e. product planning, concept generation, design, CAE, prototyping, testing, etc.
- Team work.
- Presentation skill.
- Direct contact with industry and engineers.

Our student team record

- Formula SAE tour
  - 25^{th} place in 2004. (1^{st} in fuel economy)
  - Retired in 2005
  - 27^{th} place in 2006
- Formula Japan
  - 2^{nd} place in 2004
  - 2^{nd} place in 2005

Base engine specifications

- Honda CBR600F4i （600cc）
- In-line 4, DOHC 16-valves
- Electronic fuel injection control
- Power: 72 PS / 12,000 rpm
- Torque: 38 ft-lb / 10,000rpm

Required engine performance

- Lower speed range
- Quick response

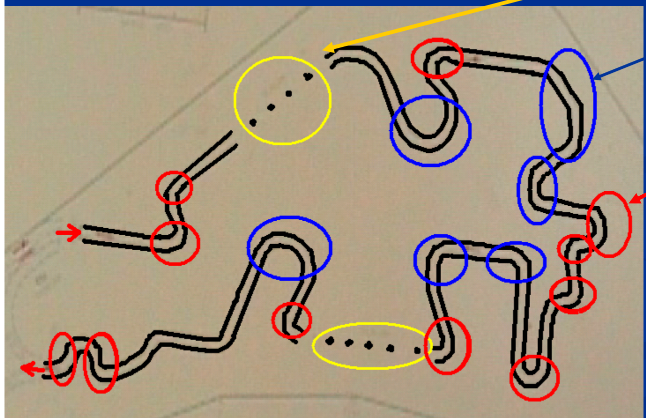
because of the racing track design and drivers' skill.

Elements of a Typical F-SAE Racing Track

Slalom

High-speed corner

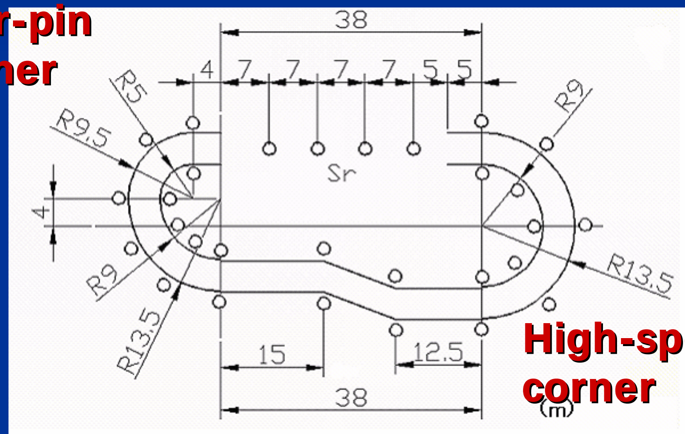
Hair-pin corner



A simplified model track for test runs

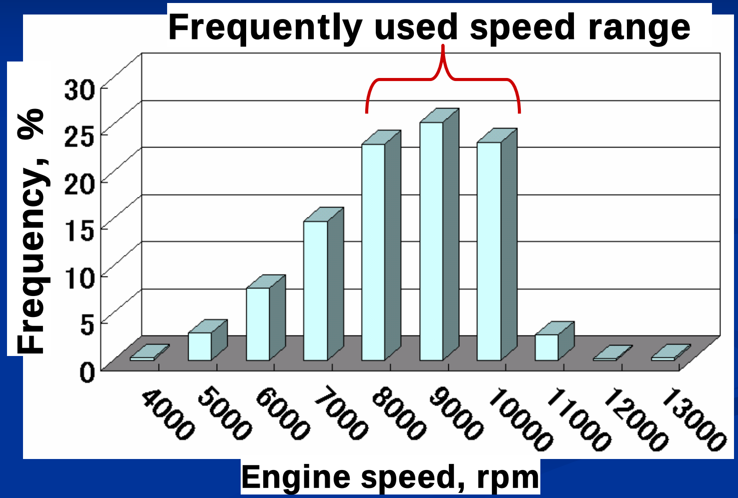
Slalom zone

Hair-pin corner



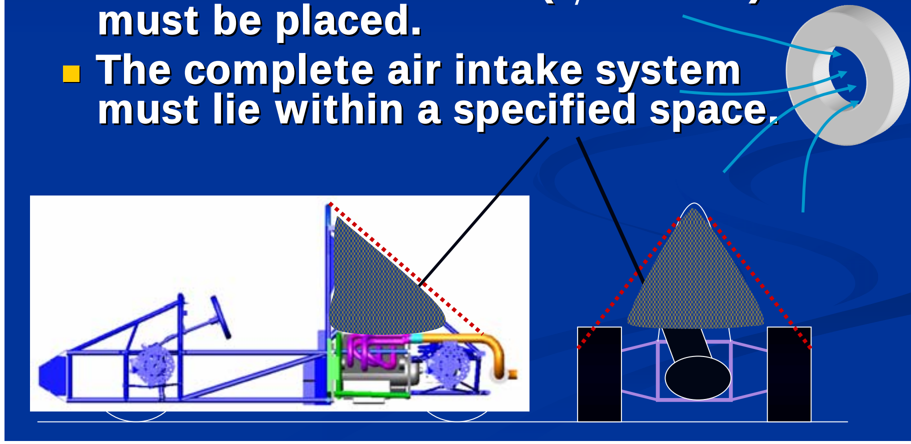
High-speed corner

Engine speed distribution on the simplified model track



Restrictions on the engine design

- Piston displacement < 0.61 liters.
- An air flow restrictor (ϕ 20mm) must be placed.
- The complete air intake system must lie within a specified space.



Design principle and Embodiment design

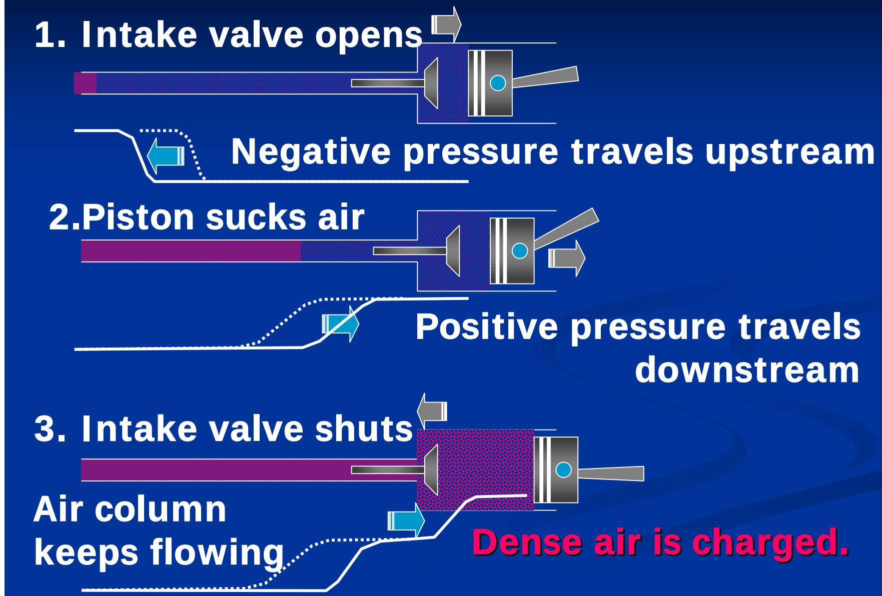
- Physical principle for realizing performance;

  "Intake air inertia effect"

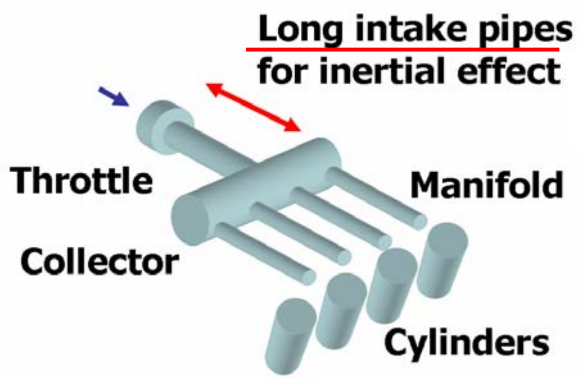
1st Step: Intake and exhaust system parametrical optimization by CAE.

2nd Step: Embodiment design that lead to contradictions.

Inertia effect



Intake pipe length tuning to use the inertia effect



at low engine speed

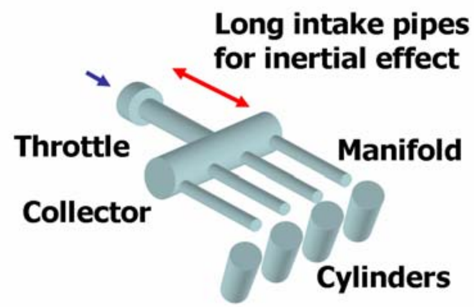
How long?

Does it within the space restriction?

Collector volume tuning

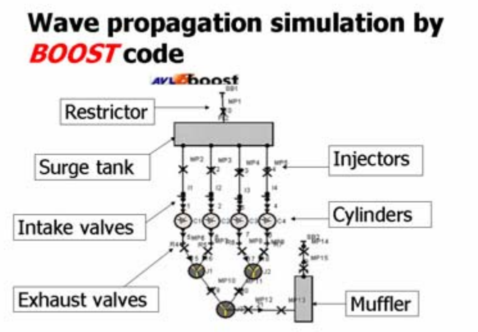
- Must be small for quick response.

Can the two requirements be satisfied at the same time?



- Must be large for uniform air distribution.

Intake system performance simulation



Quasi-one-dimensional analysis model. Shapes of elements cannot be dealt with.

- Ignoring the space restrictions, suitable values of intake pipe length and collector volume were found for the performance requirements.
- The designer (student) was able to move to embodiment design and invention quickly.

Embodiment design

A. Collector design

Necessary functions of the collector:

- To minimize pressure drop
- To give uniform air flow distribution over all cylinders.

Strategy to realize the functions:

- To slow down the air flow.
- To avoid sharp corners.
- To assure equal cross sectional area.
- To give same shapes and bents to the flow passage to each cylinder.

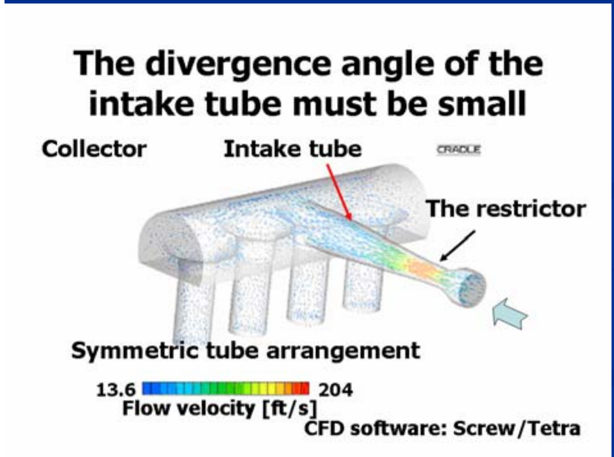
Restrictions from manufacturability and safety.

- Casting is desirable for realizing free three dimensional shape. However, no foundry was available.
- Fiber-reinforced plastic is possible. However, safety under heat and gas exposure was not clearly understood.

➡ A probable solution:
Build a collector into a cylindrical shape by sheet metal welding.

Intake tube design

- Flow velocity distribution in a computational fluid dynamics model.



This model meets performance requirements. However, it occupies too large space.

Invention by our students

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.

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

Inventive principles induced and specific ideas

#7 Nesting: An object passes through a cavity of another object.

=> Inserting the intake tube deep into the collector.

#14 Spheroidality: Replace flat surface with curved surface.

=> Hemispherical collector bulkhead to turn the airflow smoothly.

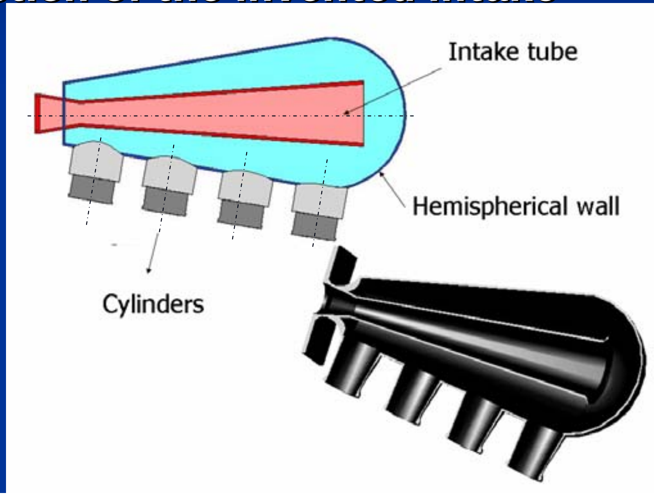
Inventive principles induced and specific ideas (continued)

#17 Moving to a new dimension: Move an object in a plane to three dimensional space.

=> designing three dimensional air flow in the collector with radial and rotational movement.

Realization of the inventive principle

- **Cross-section of the invented intake system**



Manufacturability

- Easy to build:
  Intake pipe: Lathing
  Collector shell: Sheet metal bending and welding.
- These methods of manufacturing were conceived by the student from the beginning of the invention.
- The student had plenty of hands-on experience of manufacturing.

Testing the invented intake system

Cylinder no.1 intake stroke

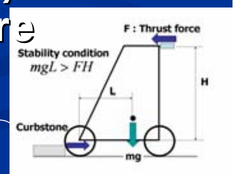
Cylinder no.3 intake stroke

- The streamlines are smooth for every cylinder intake stroke.

CASE STUDY No.2: Walking aid for outdoors

Project description

- To give more mobility to people with walking difficulties.
- To fill daily needs and to exercise, such as to go to a nearby post office, convenient stores, etc.
- Must run over rough surface and ride over gaps like motor vehicles, while giving small vibration and sure support to their users.

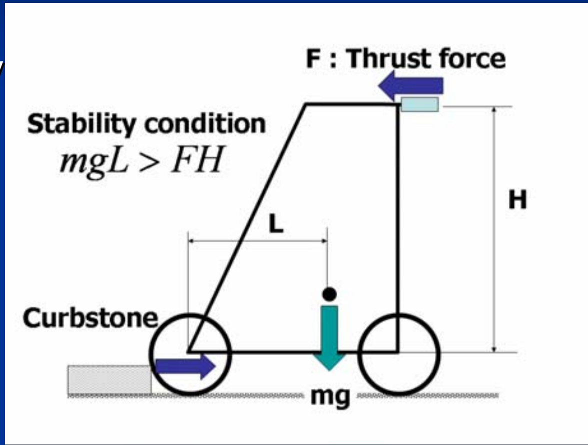


Mechanics of gap over-ride

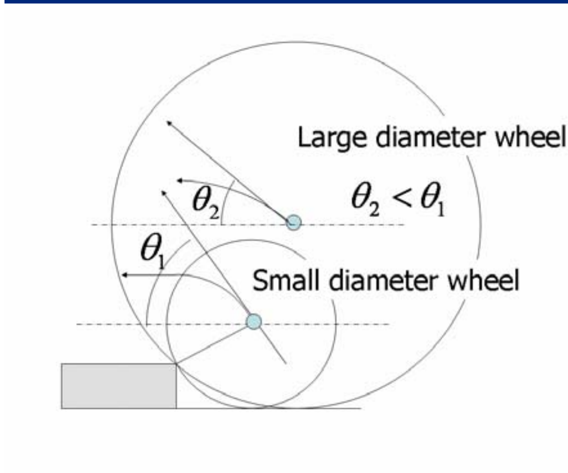
To increase pitch stability margin:

F => small

L => large



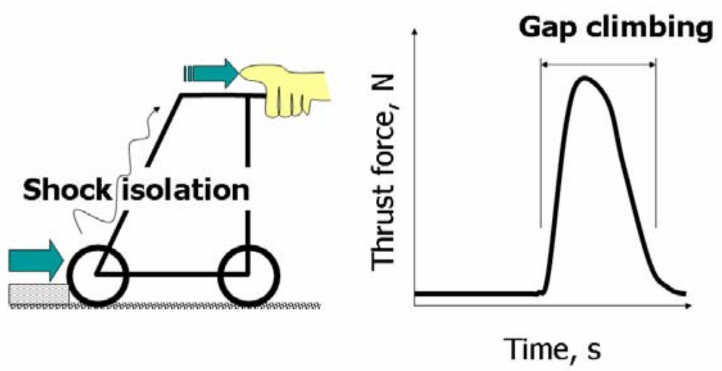
Large diameter wheel makes climbing slope gentler.



- For 50mm gap climbing, 500mm diameter is necessary.
- 500mm wheel is too large for free leg movement

Requirement of shock isolation

Large thrust → **Shock to grips**

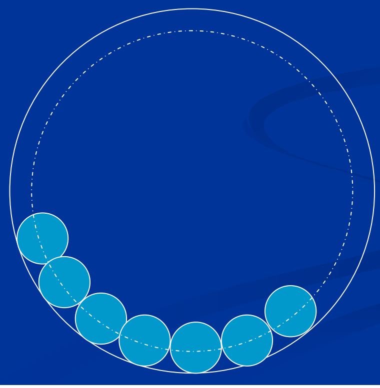


Contradictions

- Feature to change:
  - Thrust force reduction.
- Undesired result:
  - Large diameter wheel
  - Instability due to soft suspension

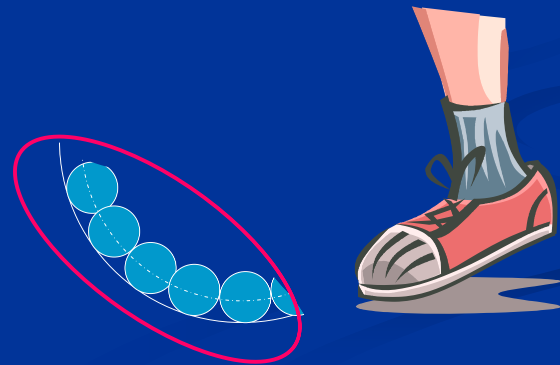
Invention principles

- Segmentation: To divide a large wheel into a number of small wheels to form a large diameter envelope circle.



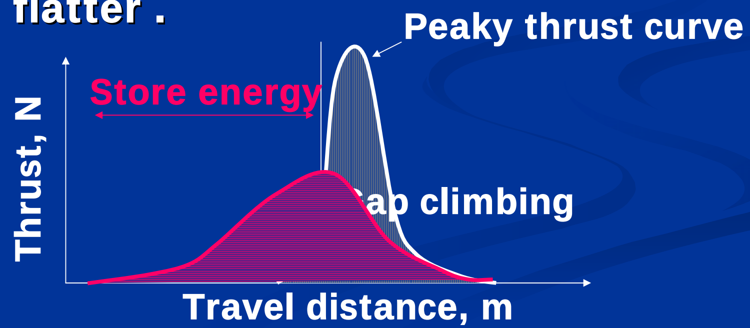
Invention principles

- Asymmetry: Use only the front part of the said envelope circle.

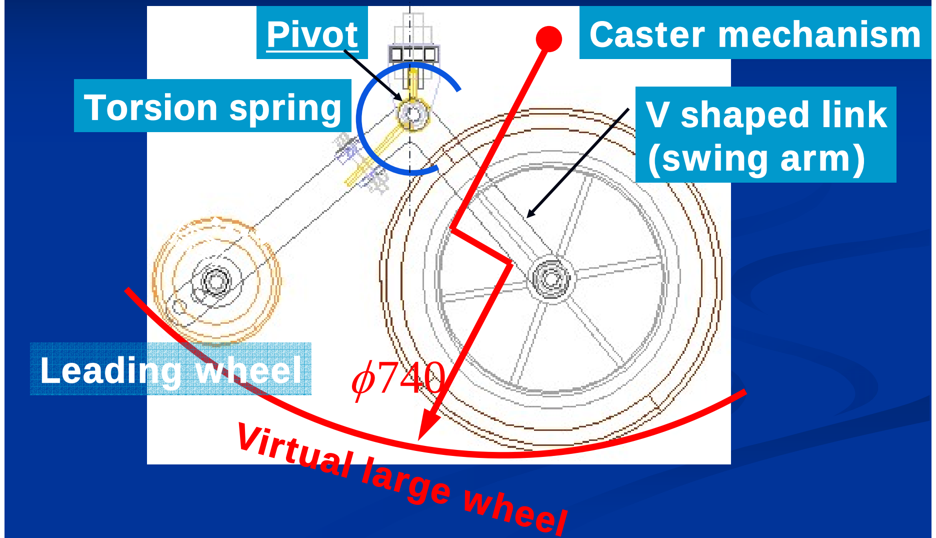


Invention principles

- 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 .



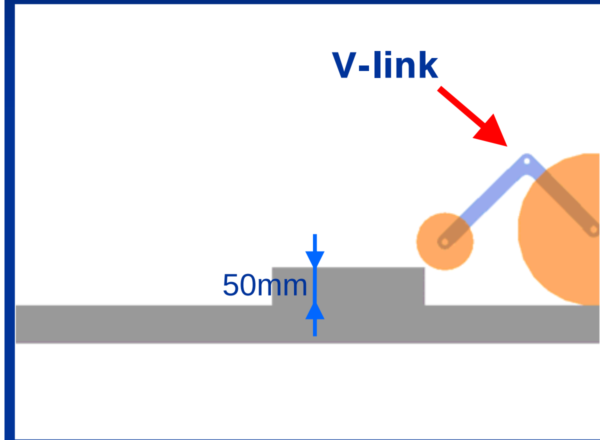
Virtual large radius wheel by enveloping multi small wheels



Testing the idea

- With CAE simulation background, the student inventor created a simulation model quickly.

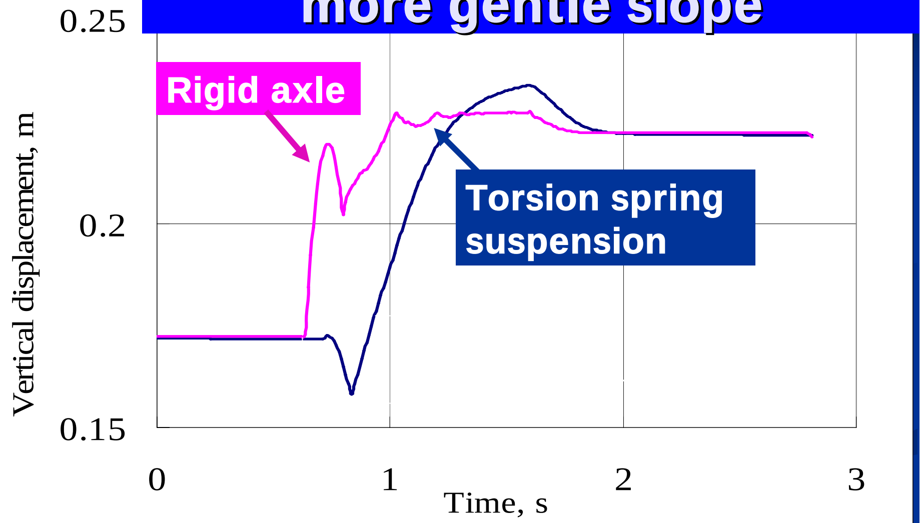
Multi-body dynamics simulation of the front wheel motion



Animated bump override simulation

Collision of the main wheel
↓
V-link swing
↓
Touch down of the leading wheel
↓
Energy accumulation in the torsion spring
↓
Energy release and gap climbing

The front suspension gives more gentle slope

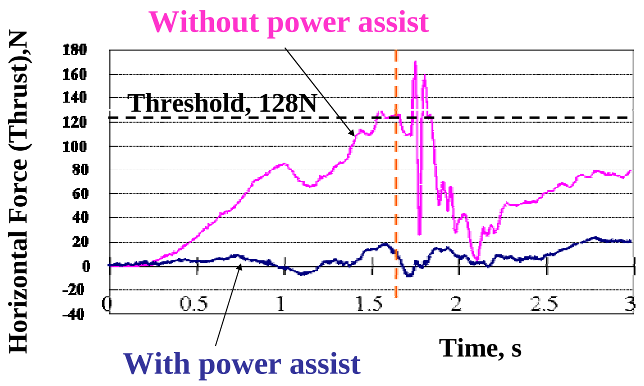


Bump height = 50mm

The prototype

The power assist performance

Measured thrust value satisfies the design specification.



Conclusions

- 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.
- Project based learning is a good environment to teach TRIZ.