Introduction

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Goals & Objectives

- Basic Understanding of Vehicle Dynamics
- Design/Assess Hands-On Exercises Utilizing Vehicle Dynamics
- Measure Vehicle/Driver Capabilities
- Develop an Objective Student Evaluation System
- Supply Accurate Feedback for Coaching the Students
The Foundation

- Basics of Vehicle Dynamics
- Understanding G’s
- Time and Distance Relationship
  - Help us explain speed
- Lateral Acceleration
- De-Acceleration
- The Chord
  - Basis of all emergency maneuvers
Introduction to Vehicle Dynamics
Vehicle Dynamics

- VD is the application of the Laws of Physics (LOP) to a vehicle in motion
- Basic principals are the same for all vehicles, makes no difference
- This is a science
  - When driving through cones, around corners, or trying not to hit something
  - When teaching others to do those things
Vehicle Dynamics

The vehicle/driver combination in motion must operate within the Laws of Physics

• A vehicle can:
  ◦ GO → Acceleration
  ◦ STOP → Deceleration
  ◦ TURN → Lateral Acceleration
Vehicle Dynamics

• A vehicle really can do any of these five things:
  ◦ GO
  ◦ STOP
  ◦ TURN
  ◦ GO & TURN
  ◦ STOP & TURN
Inputs & Outputs

- The drivers inputs are:
  - Acceleration / Speed  (Go)
  - Braking           (Stop)
  - Steering          (Turn)

- The vehicle’s output is
  - Energy/Force pushing on it’s CG

- The driver’s reaction to that Energy/Force is what we can:
  - Create with specific exercises
  - Measure and evaluate
  - Coach them to improve operation
Forces on the Vehicle

Speed and Turning = Force pushing on the Cg of the vehicle

Braking = Force pushing on the CG of the vehicle
Introduction to G’s
The Force (G’s)

- The forces are measured in G’s
- G’s are the result of the vehicle’s ability combined with the driver’s inputs
  - In response to emergencies
  - Negotiating driving exercises
- G forces are most noticeable when the car is approaching its limits
- Three responses when reaching these limits
  * Oversteer  * Understeer  * Neutral Steer
Oversteer

- NASCAR calls this “loose”
- The condition where your rear tires lose adhesion while your front tires remain in contact with the pavement in a turn or emergency maneuver
- The back end of the car tends to slide out
Basic Handling Oversteer
Basic Handling Oversteer

What is the Vehicle Capable of?

- 1000 lbs
- 1600 lbs
- 3200 lbs

A vehicle will START to oversteer (or understeer) before it reaches its max potential.

It will START to send signals to the driver at approximately 40% to 50% of its capability.

A MAJOR TEACHING POINT
Understeer

- NASCAR calls this "push"
- The condition where the front tires lose adhesion while the rear tires remain in contact with the pavement in a turn or emergency maneuver
- Front tires slide forward
A progression
Can happen slow – or quick
Slow = 2 Seconds
Quick in tenths of seconds

Basic Handling Understeer
Basic Handling - LOP

4000 POUND CAR CAN ABSORB 80% OF ITS WEIGHT

$0.8 \times 4000 = 3200$ POUNDS

This 3200 pounds is pushing on the Center of Gravity of the Vehicle

THINK OF A SEE SAW
Introduction to Lateral Acceleration
Newton’s 3rd Law of Motion

“For every action there is an equal and opposite reaction”

- When a force pushes on the Center of Gravity (CG) of the vehicle
- There will be an equal and opposite force pushing back on the CG
Newton’s 3rd Law of Motion

- The amount of force (energy) is determined by how much gas or brake is applied when the steering wheel is moved.
- The more speed or brake combined with steering, the more energy or force is placed on the vehicle.
- We know that controlling those forces is not as easy as it seems.
Lateral Acceleration

• This force (G’s) has a scientific name - Lateral Acceleration

• The acceleration that is created when a vehicle corners

• How does this force get to the vehicles CG?

• What does the driver do to create this force?
Vehicles are designed to accept a maximum amount of LA G’s (force pushing on the CG).

This G number is what defines the vehicle’s handling (evasive maneuvering) capability.

The higher the number, the better the handling and evasive capability.

If a vehicle can handle at .8 G’s it means it can take up to 80% of it’s weight pushing on the CG while turning the vehicle.
<table>
<thead>
<tr>
<th>Car Model</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porsche</td>
<td>0.95 G’s</td>
</tr>
<tr>
<td>Corvette</td>
<td>0.94 G’s</td>
</tr>
<tr>
<td>Dodge Police Charger</td>
<td>0.87 G’s</td>
</tr>
<tr>
<td>Ford CVPI (2002 and older)</td>
<td>0.85 G’s</td>
</tr>
<tr>
<td>Ford CVPI (2003 and newer)</td>
<td>0.80 G’s</td>
</tr>
<tr>
<td>Chevy Suburban</td>
<td>0.74 G’s</td>
</tr>
<tr>
<td>Ford Explorer</td>
<td>0.66 G’s</td>
</tr>
<tr>
<td>Armored Suburban</td>
<td>0.60 G’s</td>
</tr>
<tr>
<td>Armored Bear Cat</td>
<td>0.34 G’s</td>
</tr>
<tr>
<td>Indy Car</td>
<td>4.0 G’s</td>
</tr>
</tbody>
</table>

Above numbers are for dry pavement.
Where Can I Get The Numbers?

- Find them on the internet
- Use an on-board computer
- There are ways you can calculate the Handling Capability of vehicles
- If you have two identical vehicles
  - They could have different handling capabilities
- Cannot effectively train, to an objective standard, if you don’t know what the vehicles are capable of
Ford CVPI can handle at .8 G’s
It weighs 4000 pounds

It can absorb 80% of its weight
\[ .8 \times 4000 = 3200 \text{ pounds} \]

This 3200 pounds is pushing on the Center of Gravity of the Vehicle

THINK OF A SEE SAW
Introduction to VDI’s Driver Evaluation Process
Phase 1
It’s Not JUST the Vehicles Capability That Concerns Us

- How much of the vehicle can the student use?

THE AVERAGE DRIVER USES ONLY 40% OF THE CARS CAPABILITY

- How much of the vehicle can your student use?
Measuring G’s
The Foundation of Training

G’s will be used to:

• Set goals
  ◦ The percentage of LA the student must use

• Create standards
  ◦ Created by the engineering community

• Measure driver competencies
  ◦ Levels of competencies set by
    • The safety community
    • Engineering community
Radius

- We all know what the term Radius means
- Where do we use it in driver training?
  - Radius is the path the front wheels take when the steering wheel is turned
  - What radii are available?
  - What radius is optimum?
- This radius is utilized to calculate the Lateral Acceleration of the car
Radius

The more the steering wheel is moved the smaller the radius

The Radius is measured in feet
Key Equation - LA

LA = \frac{V^2}{R} \times 15

- LA = Lateral Acceleration (G’s)
  Force acting on the CG of the car

- V = Velocity - Speed in MPH

- R = Radius - Measured in feet
Problem #1

- The car will handle .84 G's
- A student enters an exercise with a radius of 150 feet,
- Traveling 40 mph, will they make it?

\[ LA = \frac{V^2}{R \times 15} \]
\[ LA = \frac{(40 \times 40)}{(150 \times 15)} \]
\[ LA = \frac{1600}{2250} \]
\[ LA = .71 \]

- SKILLFUL DRIVER - YES
#1 - Using the Vehicle

- If the car can handle .84 G’s
- The driver reached .71 G’s
- How much of the car is the driver “using”
- \( \frac{.71}{.84} \) or 85% of the car’s capability
- Is that good? Is it easy?
Problem #2

- Student enters a corner with a radius of 75 feet at 30 mph. Same car - can take .84 G’s

- Will they make it?

- \[ LA = \frac{30 \times 30}{75 \times 15} \]
- \[ LA = \frac{900}{1125} \]
- \[ LA = .80 \text{ G’s} \]

- The student is using \[ .80 / .84 = 0.95 \text{ or 95\% of the vehicle} \]
Problem #3

- Car can take .84 G’s corner is the same 75 foot radius - except they enter at 32 mph - less than 10% increase in speed

- \[ LA = \frac{(32 \times 32)}{(75 \times 15)} \]
- \[ LA = \frac{1024}{1125} \]
- \[ LA = .91 \text{ G’s} \]

or \[ .91 / .84 \] which is 108% of the vehicle (it’s going to be exciting)
Lateral Acceleration

\[ LA = \frac{V^2}{R} \times 15 \]

\[ R = 80 \text{ Feet} \]

\[ V = 30 \text{ MPH} \quad G'\text{s } \underline{0.75} \quad ? \]

\[ V = 35 \text{ MPH} \quad G'\text{s } \underline{1.02} \quad ? \]

\[ R \text{ is changed to } 100' \]

\[ V = 26 \text{ MPH} \quad G'\text{s } \underline{0.45} \quad ? \]

\[ V = 34 \text{ MPH} \quad G'\text{s } \underline{0.77} \quad ? \]
Small Changes in Speed

- Student drives through a slalom that has a 100 Foot radius
- You give the speed of 30 MPH \(0.60\) G
- Then 34 MPH \(0.77\) G
- Then 38 MPH \(0.96\) G
- Then 40 MPH \(1.06\) G
Very Big Changes in LA G’s

- LA = $V^2/R15$

- Doubling the speed of a car doesn't double the Lateral Acceleration force exerted on the car, it quadruples it!

- It’s not the amount of the speed (20 mph, 30 mph...) it is what the speed produces in LA G’s pushing on the vehicle CG

- When the student goes from 20 mph to 40 mph, it's really like going from 20 mph to 80 mph!

- It could be more G’s than the car can handle
Cord & Cord Equation

- The Cord is utilized in a method to determine a Radius
- By solving the Cord Equation we can calculate the Radius a vehicle takes when driving:
  - Through an exercise, or
  - Around an obstacle
- Remember Radius and Lateral Acceleration from earlier?
  - $LA = \frac{V^2}{R} \times 15$
How do we find $R$ if it is not known

$$R = \left( \frac{C^2}{8 \times M} \right) + \frac{M}{2}$$

- $R =$ Radius
- $C =$ Chord
- $M =$ Middle Ordinate

The Middle Ordinate is measured out from the center of the Cord.
This distance is the Cord

This distance is the Middle Ordinate
Cord & Middle Ordinate

Used to determine the radius a vehicle takes when moved from its straight line path.
Radius for the Slalom

- $R = \left( \frac{C^2}{8 \times M} \right) + \frac{M}{2}$
  - $R = \text{Radius}$
  - $C = \text{Chord – distance between cones}$
  - $M = \text{Middle Ordinate} - \frac{1}{2} \text{the width of car}$

- The further apart the cones, the larger the radius

- What is the distance utilized in your slalom?
Radius for the Slalom

Chord = distance between the cones

CHORD

M = ½ THE WIDTH OF THE VEHICLE
If Know The Radius

- If you know:
  - Vehicle’s maximum G capability
  - Radius the vehicle must take
- The max speed at which the vehicle can run the course can be calculated

\[
\text{Speed} = \sqrt{R \times G's \times 15}
\]

- Speed in mph
- \( R \) = Radius in feet
- \( G's \) = Vehicle’s maximum G capability
- 15 is the constant
If Know The Radius

- Slalom exercise with a radius of 100 feet
- Vehicle’s maximum G’s is .65
- What is the maximum speed for the exercise?

\[
\text{Speed} = \sqrt{R \times G \times 15}
\]

\[
\text{Speed} = \sqrt{100 \times 0.65 \times 15}
\]

\[
\text{Speed} = \sqrt{975}
\]

\[
\text{Speed} = 31.22 \text{ mph}
\]
If Know The Radius

- Computed – from the Chord Equation – the radius is 110 Feet
- The vehicle handles at .8 G’s
- What is Maximum Speed?

\[ \text{Speed} = \sqrt{R \times G \times 15} \]

\[ \text{Speed} = \sqrt{110 \times 0.80 \times 15} \]

\[ \text{Speed} = \sqrt{1320} \]

\[ \text{Speed} = 36.33 \text{ mph} \]
The Real World

- You Don’t Pick the Chord
- You don’t pick the approach Speed
  - You can change it once you recognize a problem
- You are given a Radius you must drive through
  - Dictated by the environment & situation
  - You can use it to your maximum advantage
- Train the student to deal with the hand they have been dealt
Introduction to VDI’s Driver Evaluation Process
Phase 2
Driver Evaluation

- A effective way to characterize vehicle/driver performance is measuring g’s
- Use acceptance
- Willingness to use the vehicle
- The driver capability envelope
- Using the vehicle
What Is A Good Driver?

- What is good and not good?

- Two ways of measuring vehicle driver capability:
  - Equipment
  - Empirical

- What is:
  - Good
  - Passable
  - Minimum
What Is A Good Driver?

- Remember that the average driver uses only 40% of the car’s capability.
- What goal do you want your students to reach?
  - 40%
  - 50%
  - 60%
  - 70%
  - 80%
- What is passing?
- What is failure?
What Is A Good Driver?

- Use the Lateral Acceleration G’s as a guide to measure the students performance

- Example of percentage values of G’s for a vehicle with 1 G maximum
  - .80 g’s good driver or 80%
  - .40 g’s for average driver or 40%
  - .30 g’s for inexperienced driver or 30%
    - (Should consider walking)
Success Depends On

- How the driver and the vehicle react to the forces involved

- Important to separate the two
  - Driver
  - Vehicle

- Our Job
  - Create those forces
  - Measure those forces
  - Explain those forces
  - Control those forces
If You Know

- The Radius of the curve
- Speed at which the student takes the radius
- You can calculate the vehicle’s and driver’s performance
- Our goal is to evaluate the driver’s performance based on a uniform objective standard
Slalom Evaluation Process

- You know:
  - CVPI maximum G capability is .80
  - Radius is calculated to be 110 feet

- What is the max speed at which the vehicle can run the course?

\[
\text{Speed} = \sqrt{R \times G \times 15}
\]

\[
\text{Speed} = \sqrt{110 \times 0.8 \times 15}
\]

\[
\text{Speed} = \sqrt{1320}
\]

\[
\text{Speed} = 36.33 \text{ mph}
\]
Slalom Evaluation Process

- CVPI Max speed is 36 mph
- Make a chart with percentage speeds listed
  - 100 % = 36 mph
  - 95% = 34 mph \((36 \times .95 = 34.2)\)
  - 90% = 32 mph
  - 85% = 30 mph
  - 80% = 28 mph
  - 75% = 27 mph
  - 70% = 25 mph
Evaluation Process

- This same method can be utilized for evaluating the students' performance on:
  - Evasive Lane Change
  - Collision Avoidance
  - Line of travel in a curve
  - Any exercise that has a radius path of travel in it
Introduction to Time and Distance
Time & Distance

- Driving is managing time and distance
- In an emergency, survival comes down to two simple questions
  - How much time does the driver have to avoid the problem?
  - How much distance does the driver have to avoid the problem?
Time & Distance

This is simple - BUT

- We measure time and distance by using the car's speedometer

- The speedometer indicates the time it takes to cover a given distance - measured in miles per hour (MPH)

- MPH is the common unit of reference that every driver is familiar
For Driver Training using MPH is not the best reference for measuring time and distance.

When driving through an exercise or avoiding a crash, the student does not have a mile or an hour to make a decision.

“Stuff” happens in feet and in seconds.

Need the ability to convert MPH to Feet per Second (FPS).
Key Equation – MPH to FPS

- MPH X 1.47 = FPS
  - MPH = miles per hour
  - FPS = feet per second
  - 1.47 constant  \( \text{(but let’s use 1.5 to make it easier)} \)

- 20 MPH X 1.5 = 30 FPS
  - Or half of 20 is 10
  - 20 + 10 = 30

- 30 MPH X 1.5 = 45 FPS
  - Or half of 30 is 15
  - 30 + 15 = 45

- 40 MPH X 1.5 = 60 FPS
  - Or half of 40 is 20
  - 40 + 20 = 60
### Time & Distance

mph X 1.47 = fps

<table>
<thead>
<tr>
<th>SPEED</th>
<th>DISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mph</td>
<td>29.4 fps</td>
</tr>
<tr>
<td>30 mph</td>
<td>44.1 fps</td>
</tr>
<tr>
<td>40 mph</td>
<td>58.8 fps</td>
</tr>
<tr>
<td>50 mph</td>
<td>73.5 fps</td>
</tr>
<tr>
<td>60 mph</td>
<td>88.2 fps</td>
</tr>
<tr>
<td>70 mph</td>
<td>102.9 fps</td>
</tr>
</tbody>
</table>
Key Equation – FPS to MPH

- FPS / 1.47 = MPH
  - MPH = miles per hour
  - FPS = feet per second
  - 1.47 constant

- 30 fps / 1.47 = 20.4 mph
- 45 fps / 1.47 = 30.6 mph
- 60 fps / 1.47 = 40.8 mph
Going 40 mph you are traveling at 60 fps

How far would you travel in a half of a second (.5 sec)?

Answer:
60 ft X .5 = 30 Feet
60 ft / 2 = 30 Feet
Braking
De-Acceleration
Braking Techniques

- We discussed these yesterday
  - Remember?
- Left Foot or Right Foot
- Threshold
- Pump/Stab/Modulate
- **Trail** *(moves weight to the front)*
- **ABS**
  - Allows you to steer and maintain control of the vehicle under heavy braking loads
Braking

- Small increase in speed – big difference in stopping distance

- Increase speed from 40 to 44 mph
  - Speed has increased by 10%
  - Stopping distance has increased by 20%

- Increase speed from 40 to 50 mph
  - Speed has increased by 25%
  - Stopping distance has increased by 50%
The Braking Connection

- The steering wheel and the brake pedal are connected.
- How much you can move the steering wheel depends on the speed of the vehicle.
- The lower the speed the more you can move the steering wheel.
Braking

During an emergency it is not only how much distance needed to stop, but how much speed can you eliminate as quickly as possible.
Introduction to VDI’s Driver Evaluation Process
Phase 3
Braking Evaluation

- If you know the speed along with:
  - Time to stop; or
  - The distance to stop

- You can measure the rate of Deceleration

- Which is the Student’s braking performance
The goal is to measure the students' ability to stop the car.

There are a few methods to do this:

- Measuring speed when brakes are applied
- Measure the stopping distances or the stopping time
- With a computer in the vehicle

The student’s ability to stop the car can be measured in G's.
If You Know The Time...

- At 50 mph it takes 3.5 seconds to stop
  \[ G's = \frac{50}{3.5} \times 22 \]
  \[ G's = \frac{50}{77} \]
  \[ G's = .65 \]

- At 35 mph it takes 3.0 seconds to stop
  \[ G's = \frac{35}{3} \times 22 \]
  \[ G's = \frac{35}{66} \]
  \[ G's = .53 \]

- This is making the assumption that:
  - All the brakes are working
  - The coefficient of friction of the road stays the same
If You Know The Distance...

\[ G's = \frac{S^2}{30 \times D} \]

- At 50 mph it takes 100 feet to stop
  \[ G's = \frac{50 \times 50}{100 \times 30} \]
  \[ G's = \frac{2500}{3000} \]
  \[ G's = .83 \]

- At 40 mph it takes 150 feet to stop
  \[ G's = \frac{40 \times 40}{150 \times 30} \]
  \[ G's = \frac{1600}{4500} \]
  \[ G's = .36 \]
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