

# **A *Brief* Introduction to Locomotive Application**

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## Locomotive Application:

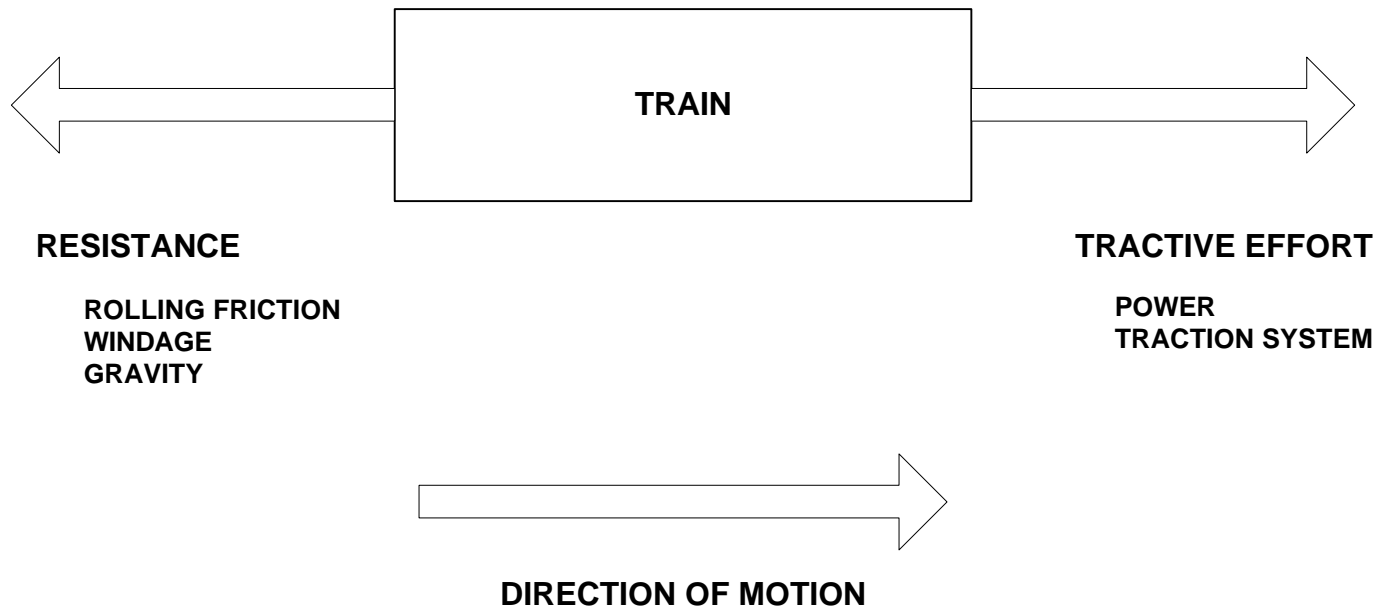
- Selecting or configuring a locomotive to best suite a customer's requirements, considering:
  - Size (clearance)
  - Weight
  - *Performance*
  - Cost (Initial & LCC)
- Determining the optimum service for a pre-existing locomotive.

## Newton's First Law

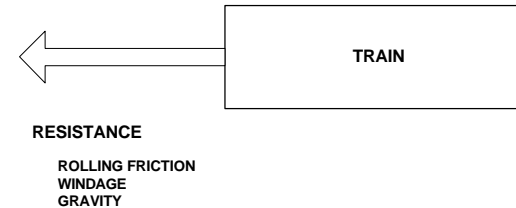
“A body in motion continues in motion unless acted upon by an unbalanced force.”

A locomotive's task is to keep a train in motion by balancing out the forces that try to stop it.

# Forces



## Resistance



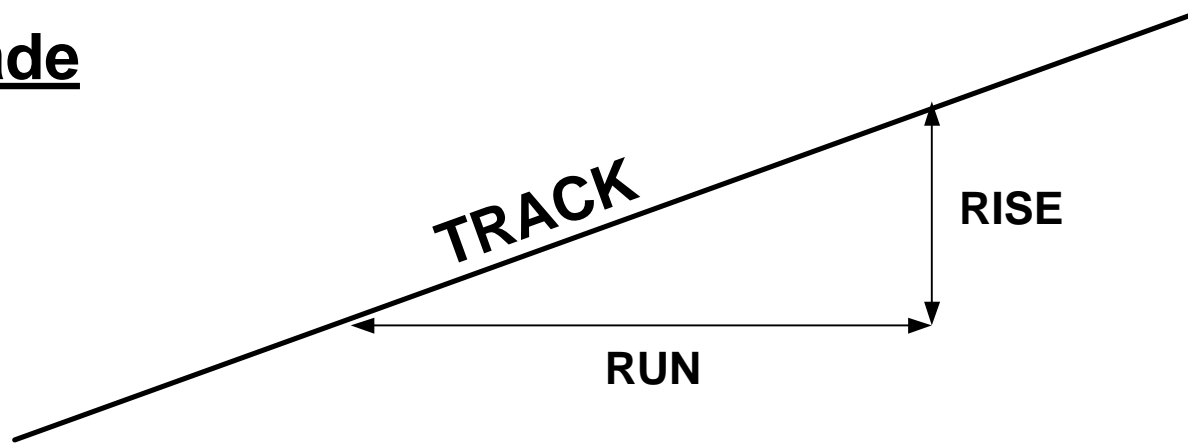
- “Davis” Equations - 1924

$$r = a + b \cdot \text{speed} + c \cdot \text{speed}^2 + d \cdot (\text{curvature}) + e \cdot (\text{grade})$$

- a = “rolling” resistance      function of bearing type, # axles, axle load
- b:= “flange” resistance      constant multiple of speed - little physical basis
- c = “wind” resistance      function of cross sectional area, ‘slipperiness
- d = “curving” resistance      constant multiple of curvature - rough approximation
- e = “grade: resistance      component of weight parallel to track

**For most GETS studies, ‘e’ overwhelms other four components.**

# Grade



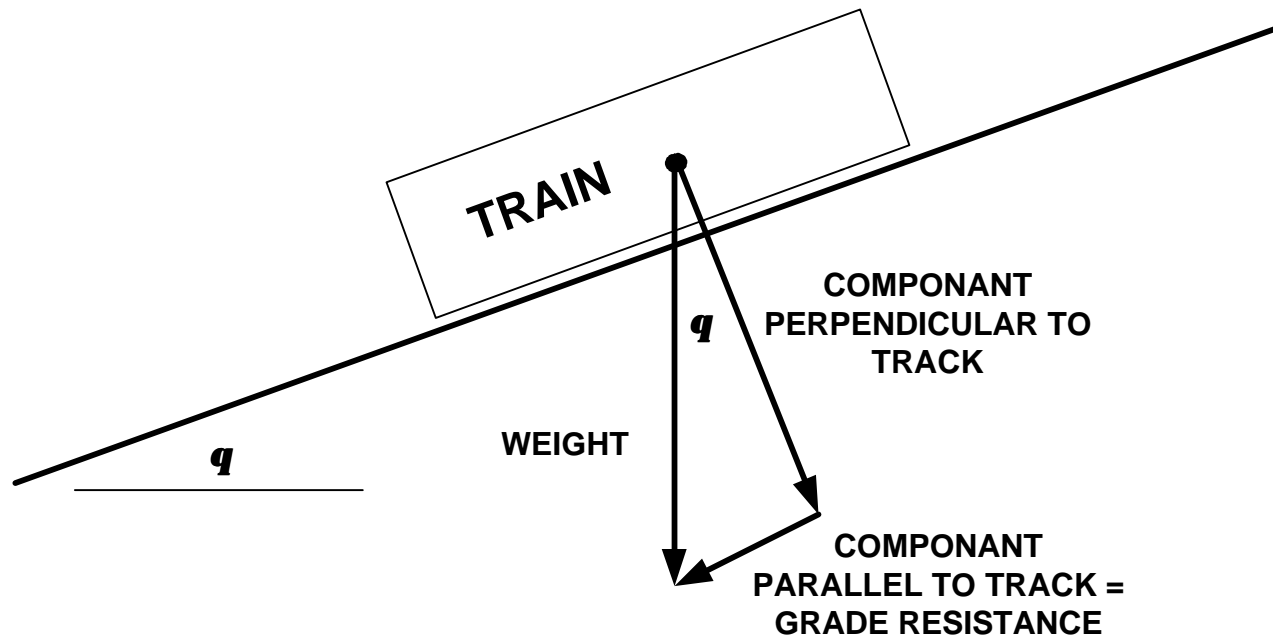
$$\text{GRADE} = \frac{\text{RISE}}{\text{RUN}} * 100\% \text{ or } \frac{\text{RISE}}{\text{RUN}} * 1000 \text{ o/oo}$$

- LEVEL = 0%
- 30 DEGREES = 58%
- 45% = 100%
- 60 DEGREES = 173%

**TYPICAL GRADES ARE < 3 %**

Insert example profile

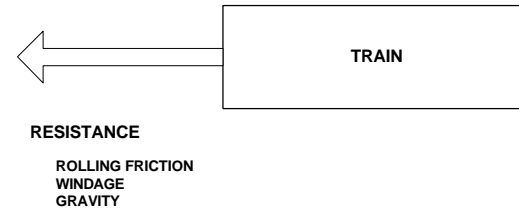
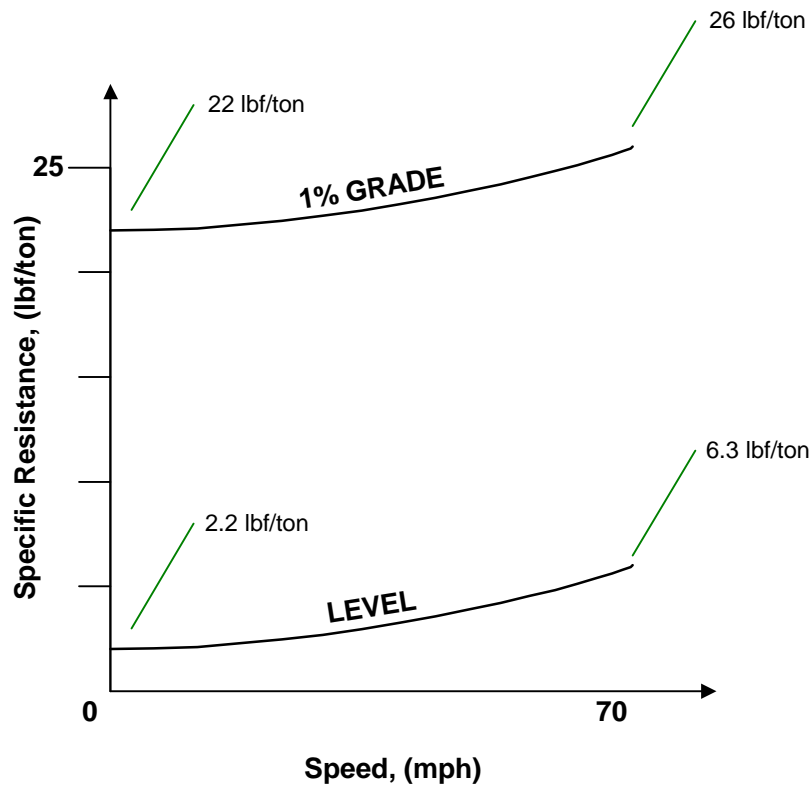
## Grade Resistance



$$GRADE\_RESISTANCE = SIN(q) \times WEIGHT \approx \frac{GRADE\_IN\_%}{100\%} \times WEIGHT$$

FOR ALL PRACTICAL GRADES  
THIS IS A GOOD APPROXIMATION

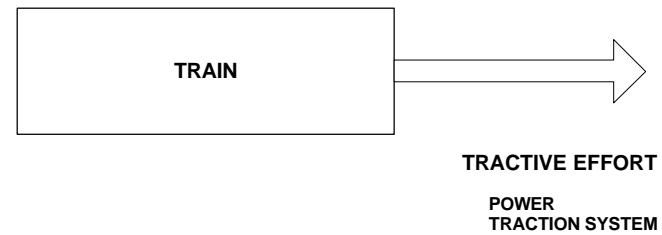
# Resistance



Resistance curves for typical freight car - 100 ton, 100 ft<sup>2</sup>, 4 axle

For low speeds, resistance can be estimated as  
 $[2.5 + 20 \cdot \text{grade}] \text{ lbf/ton}$

## Tractive Effort

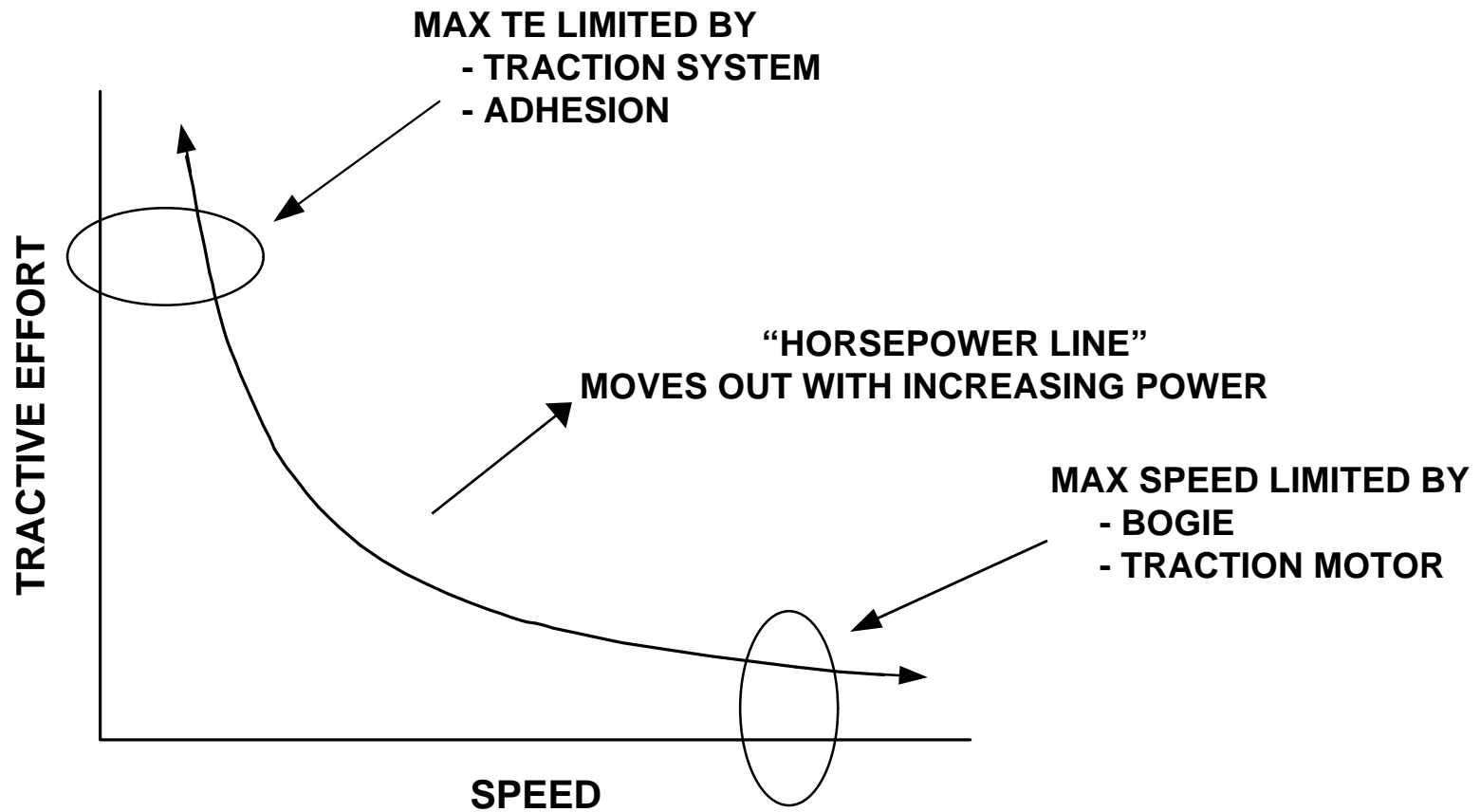


$$\text{POWER} = \text{FORCE} * \text{SPEED}$$

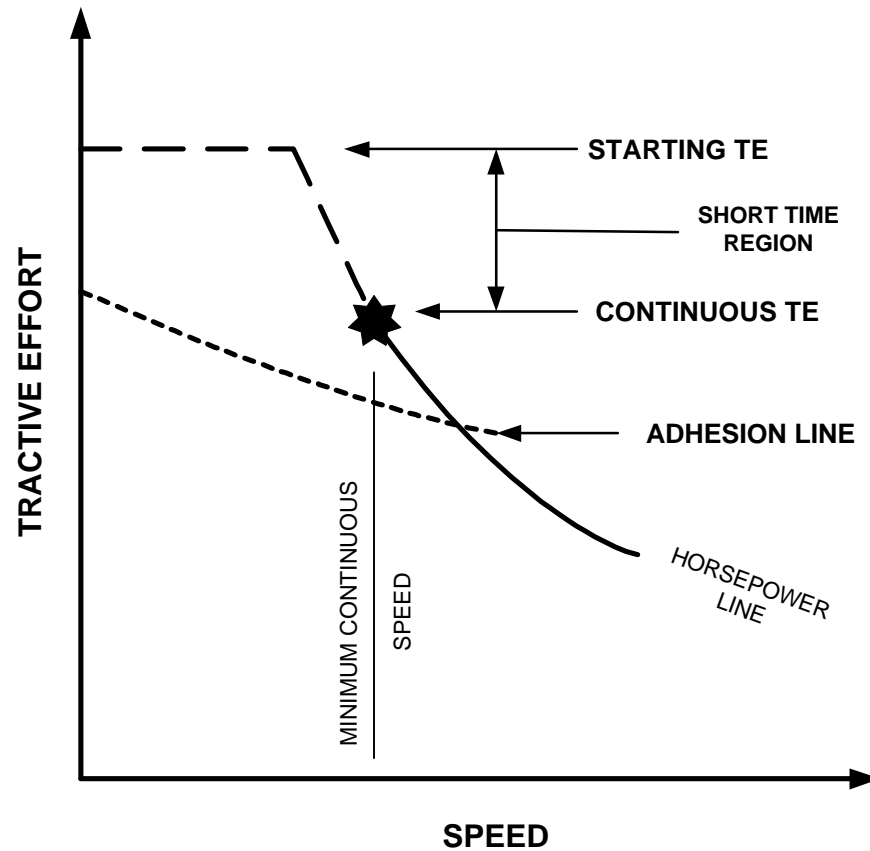
$$\text{FORCE} = \frac{\text{POWER}}{\text{SPEED}}, \text{ (UP TO A POINT)}$$

## Power distribution chart

## TE vs Speed



# TE Limits



THREE LIMITS  
STE  
CTE  
ADHESIVE TE

MOST COMPLEX ASPECT  
OF LOCO PERFORMANCE

## TE Limits - cont'd

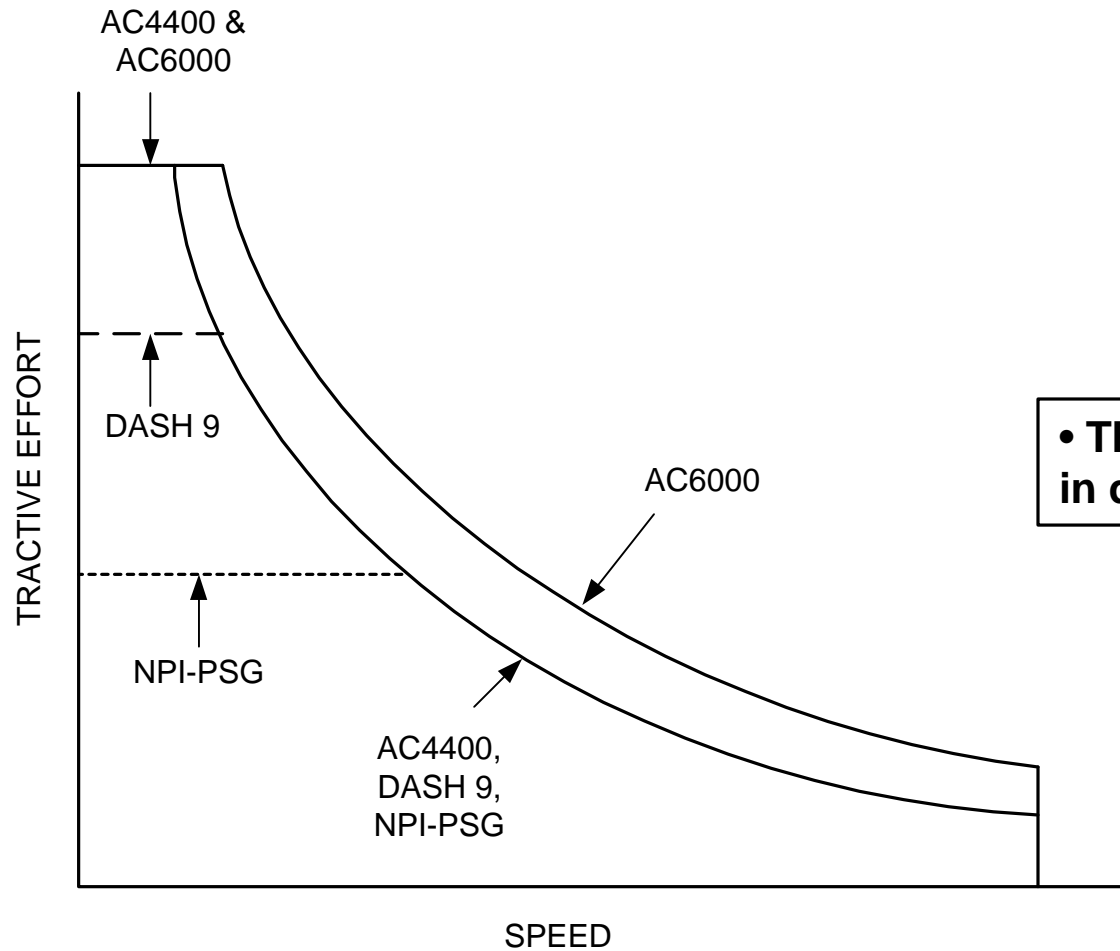
- Starting TE: Maximum possible TE  
Enforced by control system
  
- Continuous TE: Max TE with no risk of overheating  
Start of 'red zone' on operator controls  
Enforced by MTP
  
- Adhesive TE: Max TE before wheels slip  
Varies statistically with conditions  
Usually expressed as %age of weight on drivers

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<u>DASH 9</u>	<u>AC6000</u>	<u>GENESIS</u>
STE: 142,000 lbf	STE: 180,000 lbf	ATE: 84,000 lbf
ATE: 120,000 lbf	CTE: 166,000 lbf	STE: 63,000 lbf
CTE: 105,000 lbf	ATE: 135,000 lbf	CTE: 38,000 lbf

MOST RESTRICTIVE TE LIMIT VARIES  
WITH MODEL AND SERVICE

# TE Envelope



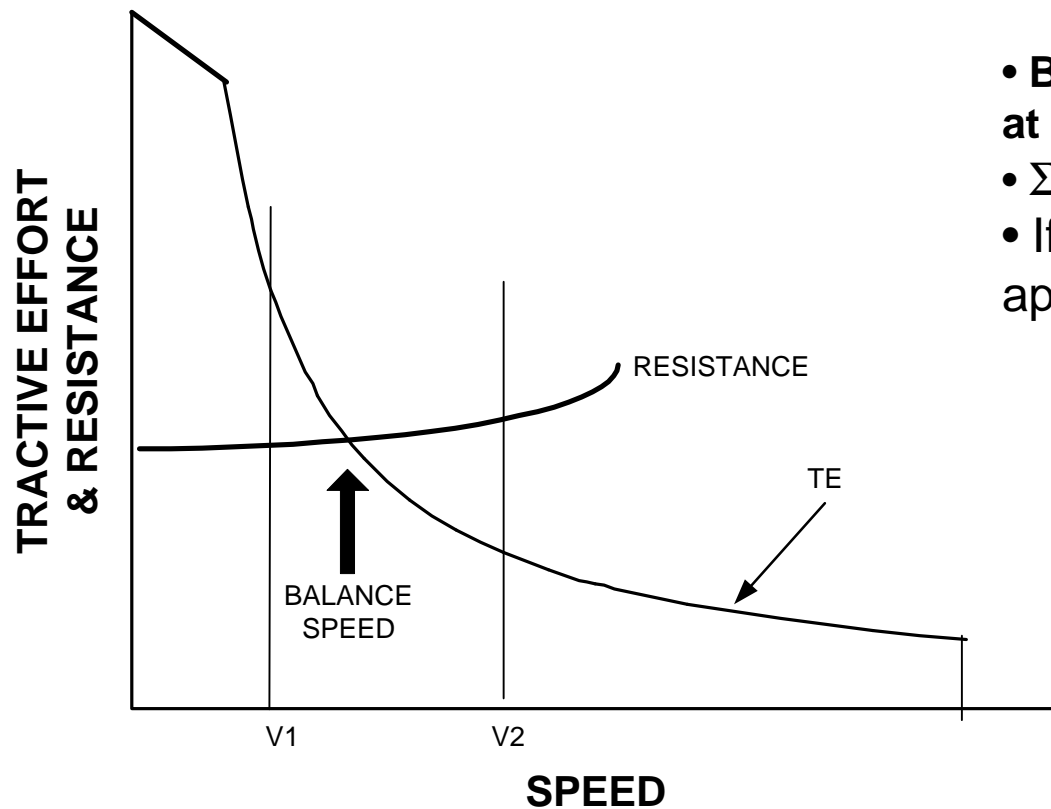
• The TE limit is completely in dependent from power.

## Newton's Second Law

$$\text{ACCELERATION} = \frac{\Sigma \text{FORCE}}{\text{MASS}}$$

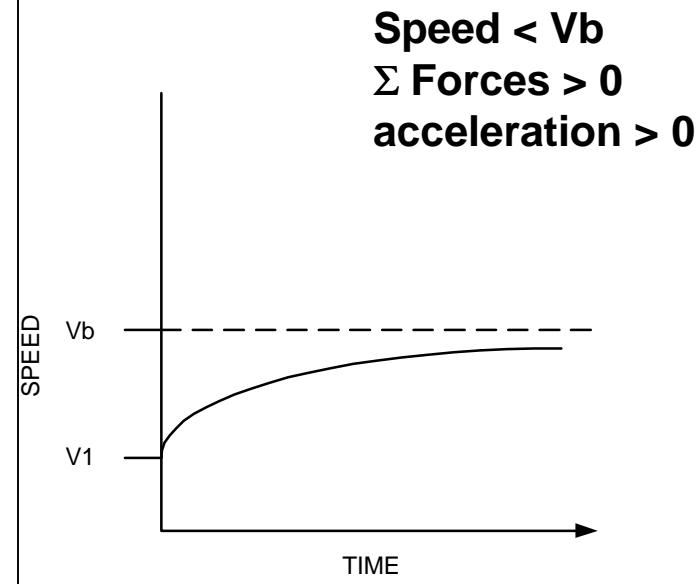
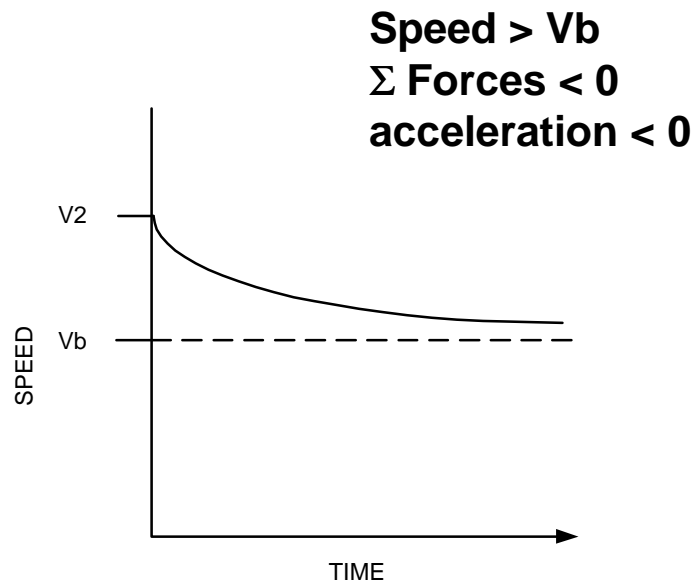
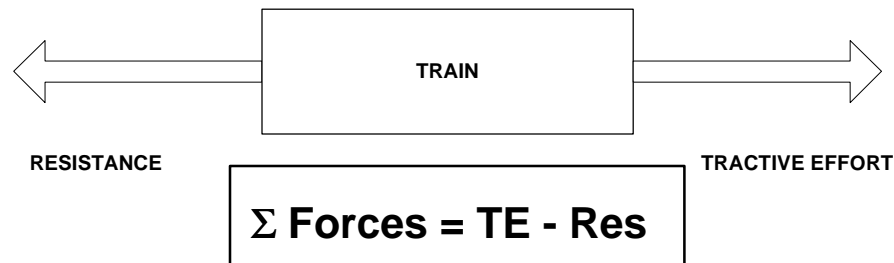
When forces don't balance, train speed changes until they do.

## Balance Speed



- Balance speed (  $V_b$  ) is the speed at which TE & resistance balance.
- $\Sigma$  Forces = 0 so Accel = 0
- If speed  $\neq V_b$ , system will approach  $V_b$ .

## Balance Speed (cont'd)



## Balance Speed (cont'd)

At balance speed

$$\Sigma \text{ Forces} = \text{TE} - \text{Res} = 0 \quad (1)$$

so that if load is specified,

$$\text{TE} = \text{Res} = r * [ \text{Tt} + \text{TI} ] \quad (2)$$

or if TE is pre-determined

$$\text{Tt} = \text{TE}/r - \text{TI} \quad (3)$$

where      Tt = trailing tons  
               TI = loco tons  
               r = specific resistance in lbf/ton

The vast majority of application work is centered around these steady-state (balance speed) equations.

**Web-based 'Quick Look Calculator' on Systems Eng'g Homepage**

## Requirement Flow-down - Example

1 loco\* / 4000 ton train must be able to achieve 50 mph on level

$$TE = r * [Tt + TI] = [4] \text{ lbf/ton} * [4000 + 200] \text{ tons} = 16800 \text{ lbf}$$

$$\text{Power @ rail} = \text{force} * \text{speed} = 2240 \text{ HP}$$

$$\text{Power for traction} = \text{RHP} / \text{trans-eff} = 2500 \text{ THP}$$

$$\text{Power at engine} = \text{THP} + \text{AHP} = 2700 \text{ GHP}$$

7FDL12 Engine Required

1 loco\* / 4000 ton train must be able to surmount short 1% grade

$$TE = r * [Tt + TI] = [2.5 + 20] \text{ lbf/ton} * [4000 + 200] \text{ tons} = 94500 \text{ lbf}$$

$$\text{Adhesion required} = 94500 \text{ lbf} / 400,000 \text{ lbf} = 24\%$$

Dash 7 or 'Brightstar' system with 6 5GE793's

\*assume 200 tons

## Capability Flow-up - Example

With what load will a B36-7\* reach 40 mph on an 0.5% grade?

$$\begin{aligned} \text{Tractive Effort @ 40 mph : given} &= 30,400 \text{ lbf} \\ T_t = TE / r - TI &= 30400 \text{ lbf} / [ 3.5 + 10] \text{ lbf/ton} - 140 \text{ tons} \end{aligned}$$

$$T_t = 2120 \text{ tons}$$

What is the maximum load 1 B36-7\* can balance on a long 2.5% grade?

$$\begin{aligned} \text{Continuous TE} &= 66,000 \text{ lbf} \\ \text{Adhesive TE} = 25\% \text{ of } 260,000 \text{ lbf} &= 65,000 \text{ lbf} \text{ LIMITING} \end{aligned}$$

$$T_t = TE/r - TI = (65000 \text{ lbf}) / [ 2.5 + 20*2.5 ] \text{ lbf/ton} - 140 \text{ tons}$$

$$T_t = 1100 \text{ tons}$$

\*assume 140 tons

Insert tonnage table

Insert tonnage curves

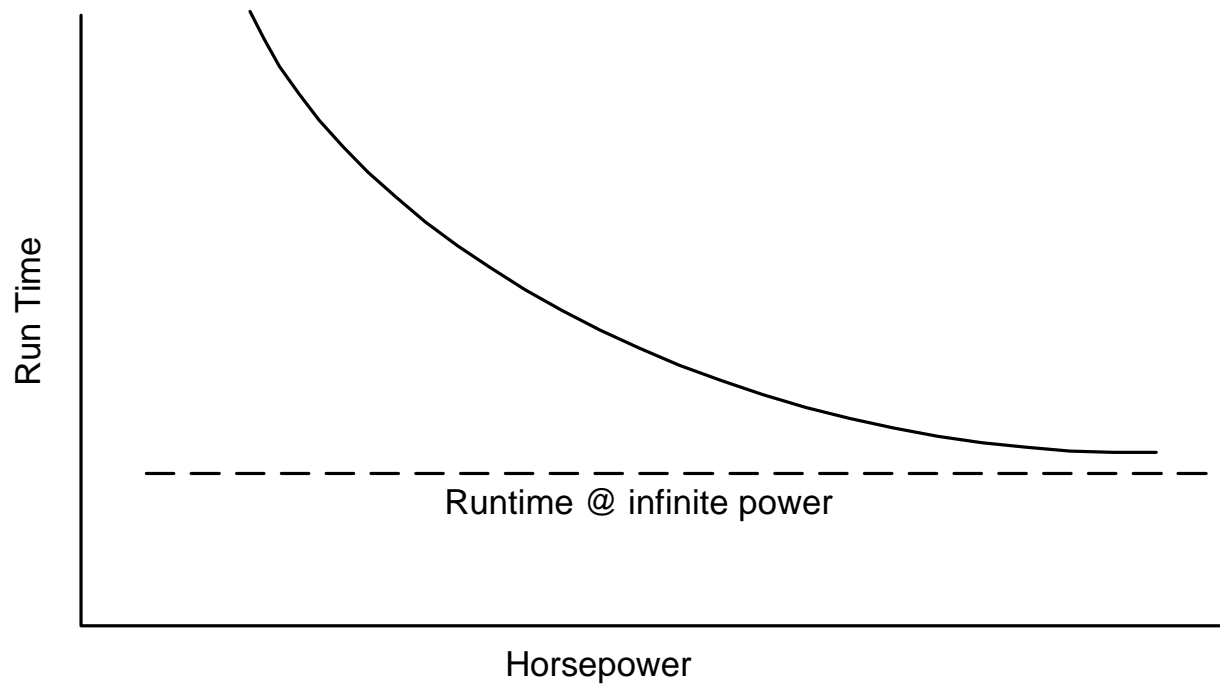
## Dispatch Practices

**Tonnage:** Trains loaded to just barely surmount 'ruling grade'  
Typically used for low value commodity goods.  
Train load dependent upon tractive effort.  
Steady state calculation adequate

**Schedule:** Trains loaded to meet a predetermined schedule  
Typically used for passenger, or priority freight.  
Train load dependent upon horsepower.  
Transient calculation required.

Insert speed / speed limit vs. distance chart

## Power Sensitivity Chart



## Some Advanced Topics:

- Dynamic braking
  - Power dissipation
  - Peak braking effort
  - Extended range & DB to 0
- Power
  - Regulation schemes
  - Auxiliary & HEP loads
  - Deration
- Fuel Consumption
  - Duty cycle matrix
  - Over the road prediction
- TE envelope configuration
  - Gearing
  - Transition
  - Field shunting
  - Plug Loading
  - Voltage/POT limits
- Drawbar force
  - Distributed power
  - Slack action
- Acceleration
  - Engine load delay
  - Transient TE curve
- GETS rules of thumb
  - Standard Conditions
  - Momentum grades
  - NHF weight
  - Adhesion
  - Averaged Effective Grade
- Analytic Methods
  - Dynamic (transient) simulation
  - Profile coding tools
  - MTP post-processors
  - Standing-start ACCELO