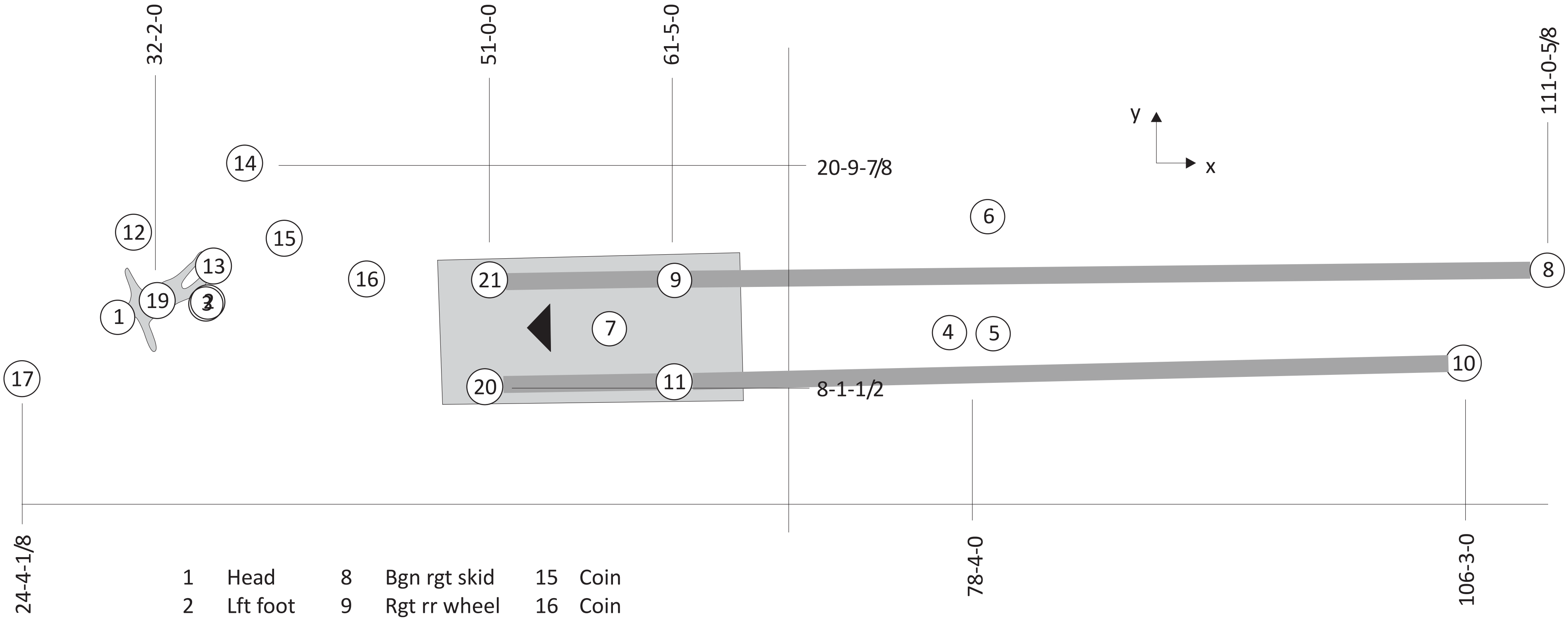
**CAARS Seminar, Third Quarter 2012, 28 August 2012, San Ramon, California**
**Calculations by Frank Owen and Jim Gerhardt, Alpha Omega Engineering, Inc., San Luis Obispo, California**

| | | x | | | y | | | x | y |
|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Object** | **ft** | **in** | **frac. In** | **ft** | **in** | **frac. In** | **in** | **in** |
| 1 | Head | 29 | 10 | 0.5 | 12 | | 0.375 | 358.5 | 144.375 |
| 2 | Left foot | 35 | | 0.25 | 12 | 10 | 0.375 | 420.25 | 154.375 |
| 3 | Right shoe | 34 | 6 | 0.5 | 13 | 1 | | 414.5 | 157 |
| 4 | Glasses | 77 | | 0.5 | 11 | | 0.5 | 924.5 | 132.5 |
| 5 | Lens | 79 | 7 | 0.25 | 11 | 1 | 0.5 | 955.25 | 133.5 |
| 6 | Hat | 79 | 3 | 0.5 | 17 | 9 | | 951.5 | 213 |
| 7 | Left shoe | 57 | 10 | 0.25 | 11 | 5 | 0.5 | 694.25 | 137.5 |
| 8 | Bgn rgt skd | 111 | | 0.625 | 14 | 8 | 0.25 | 1332.625 | 176.25 |
| 9 | Rgt rr whl | 61 | 5 | | 14 | | 0.875 | 737 | 168.875 |
| 10 | Bgn lft skd | 106 | 3 | | 9 | 4 | 0.75 | 1275 | 112.75 |
| 11 | Lft rr whl | 61 | 5 | | 8 | 4 | 0.375 | 737 | 100.375 |
| 12 | Coin | 30 | 9 | | 16 | 10 | 0.75 | 369 | 202.75 |
| 13 | Coin | 35 | 4 | 0.25 | 14 | 11 | 0.625 | 424.25 | 179.625 |
| 14 | Coin | 37 | 1 | 0.5 | 20 | 9 | 0.875 | 445.5 | 249.875 |
| 15 | Coin | 39 | 4 | 0.5 | 16 | 6 | 0.875 | 472.5 | 198.875 |
| 16 | Coin | 44 | | 0.75 | 14 | 1 | 0.875 | 528.75 | 169.875 |
| 17 | Coin | 24 | 4 | 0.125 | 8 | 5 | 0.5 | 292.125 | 101.5 |
| 19 | CG body | 32 | 2 | | 12 | 11 | 0.875 | 386 | 155.875 |
| 20 | Lft frt whl | 51 | | | 8 | 1 | 0.5 | 612 | 97.5 |
| 21 | Rgt frt whl | 51 | | | 14 | 2 | | 612 | 170 |
| | | | | | | | min | 292.125 | 97.5 |
| | | | | | | | max | 1332.625 | 249.875 |
| | | | | | | | | 1040.5 | 152.375 |




| | | | | | |
|---|---|---|---|---|---|
| 1 | Head | 8 | Bgn rgt skid | 15 | Coin |
| 2 | Lft foot | 9 | Rgt rr wheel | 16 | Coin |
| 3 | Rgt shoe | 10 | Bgn lft skid | 17 | Coin |
| 4 | Glasses | 11 | Lft rr wheel | 18 | missing |
| 5 | Lens | 12 | Coin | 19 | CG body |
| 6 | Hat | 13 | Coin | 20 | Lft frt wheel |
| 7 | Lft shoe | 14 | Coin | 21 | Rgt frt wheel |

# CAARS 3RD QUARTER TRAINING EXERCISE

**San Ramon, California - 28 August 2012**

Drawn by Frank Owen & Jim Gerhardt

Alpha Omega Engineering, Inc.

San Luis Obispo, CA

CAARS 3RD QTR Training - 8/28/12

Skid distance of auto:

$$d = 111\text{-}0\text{-}5/8 - 51\text{-}0\text{-}0 = 60\text{-}0\text{-}5/8 =$$

$$d = 60.05 \text{ ft}$$

$$S = \sqrt{30 \cdot f \cdot d}$$

From drag tests, $f \approx 0.7$

$S = 35.51$ mph at start of skid

Where is point of impact? Glasses and hat are at and around 78-4-0. So distances are:

Precollision: $d_1 = 111\text{-}0\text{-}5/8 - 78\text{-}4\text{-}0 - 2\text{-}0\text{-}0$ (2-0-0 assumed overhang)

$$d_1 = 30\text{-}8\text{-}5/8 = 30.72 \text{ ft}$$

Postcollision: $d_2 = 60.05 - 30.72 = 29.33$ ft

$$S_{PoI} = \sqrt{30 \cdot f \cdot d_2} = 24.82 \text{ mph}$$

Now use throw distance of pedestrian to calc impact speed.

$$d_{ped} = 78-4-0 - 32-2-0 = 46-2-0$$

$$d_{ped} = 46.17 \text{ ft}$$

<u>New</u> Intech formula

$$S_{POI} = 2.483\, d_{ped}^{0.61} = 2.483(46.17)^{0.61}$$

$$S_{POI} = 25.73 \text{ mph}$$

OR New Intech wrap formula

$$S_{POI} = 3.106\, d_{ped}^{0.57} = 3.106(46.17)^{0.57}$$

$$S_{POI} = 27.60 \text{ mph}$$

OR Searle - minimum speed

$$S_{MIN} = \sqrt{\frac{30 \cdot d_{ped} \cdot f}{1+f^2}} = \sqrt{\frac{30(46.17)\,0.7}{1+0.7^2}}$$

$$S_{MIN} = 25.51 \text{ mph}$$

(Note, using same drag factor as used for car.)

Searle - maximum speed

$$S_{MAX} = \sqrt{30 \cdot d_{ped} \cdot f} = \sqrt{30(46.17)0.7}$$

$$S_{MAX} = 31.14 \text{ mph}$$

Brach & Brach suggest a "hybrid wrap model":

$$S_{POI} = C_W \sqrt{d_{ped}}$$

where $C_W = 2.5, 3.6, 4.5$ & $d_{PED}$ is in meters & $S_{POI}$ in m/sec. With these units, $C_W$ must have units $\left(\frac{m}{sec}\right)/\sqrt{m}$.

We want mph$/\sqrt{ft}$. So

$$\left(\frac{\cancel{m}}{sec}\right)/\cancel{\sqrt{m}} \cdot \frac{\cancel{\sqrt{m}}}{\sqrt{3.28\,ft}} \cdot \frac{3.28\,ft}{\cancel{m}} =$$

$$= \frac{\cancel{ft}}{\cancel{sec}} \sqrt{3.28} \; \frac{1}{\sqrt{ft}} \cdot \frac{mph}{1.467\,\cancel{ft/sec}}$$

$$= 1.23 \; \frac{mph}{\sqrt{ft}}$$

This factor converts $\frac{m/sec}{\sqrt{m}}$ to $\frac{mph}{\sqrt{ft}}$

So $2.5, 3.6, 4.5 \longrightarrow 3.08, 4.23, 5.54$

m/sec$/\sqrt{m}$ → mph$/\sqrt{ft}$

Applying this

$$S_{MIN} = 3.08\sqrt{46.17} = 20.93 \text{ mph}$$

$$S_{PROBABLE} = 4.23\sqrt{46.17} = 28.74 \text{ mph}$$

$$S_{MAX} = 5.54\sqrt{46.17} = 37.64 \text{ mph}$$

Note that this method presumes no f for the pedestrian.

Thus the different estimates for collision speed actually are in a fairly narrow range of values with the best guesses being

24.81 mph (skid to stop)
25.73 mph (new Intech)
27.60 mph (new Intech wrap)
28.33 mph (Searle mean)
28.74 mph (hybrid wrap)

The average value is $S_{POI} = 27.04$ mph

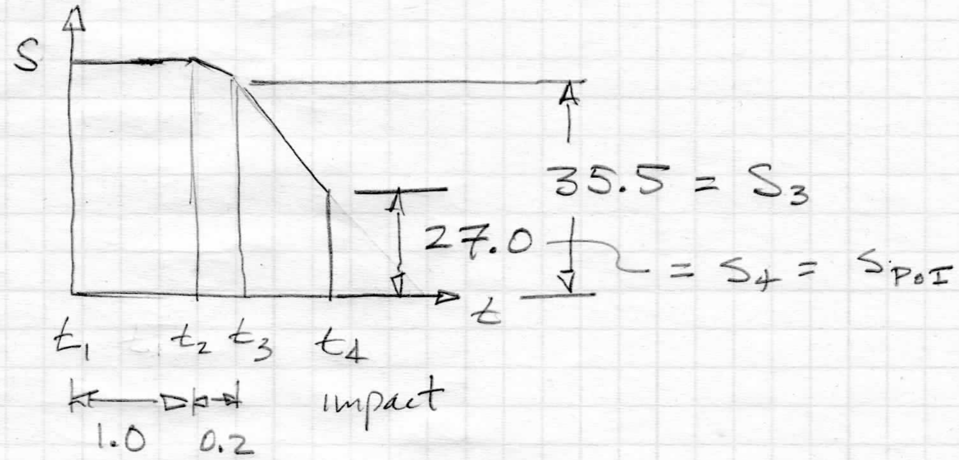
The question is often posed, "What is the maximum speed the vehicle could have been going at the time the driver saw the pedestrian so that the vehicle could have been brought to a stop before hitting the pedestrian?"

To answer this, one needs to know the time before impact that the driver saw the pedestrian. This time is braken down into three phases:

1. Driver perceives pedestrian
2. Driver initiates braking
3. Driver applies full braking

These reaction times vary according to the literature. For demonstration purposes, use $t_{12} = 1$ sec, $t_{23} = 0.2$ sec. During $t_{12}$, the vehicle rolls at its pre-braking velocity. During $t_{23}$, full braking is linearly applies, so the average braking is use, i.e. half of full braking.

If we plot S vs t




The pre braking speed, $S_1$, can be gotten from

$$S_3 = a_{23}\, t_{23} + S_2$$

where $a_{23} = -\dfrac{f}{2} g$

So $S_2 = S_3 - a_{23} t_{23} = S_3 + \frac{f}{2} g t_{23}$

$$S_2 = 35.5 \text{ mph} + \frac{0.7}{2}\, 32.2 \frac{ft}{sec^2}\, (0.2 \text{ sec}) * \frac{\text{mph}}{1.467 \text{ fps}}$$

$$S_2 = 37.0 \text{ mph}$$

The plot above of speed vs time is useful to answer the question posed about max speed at perception in order to stop before hitting the pedestrian. Note that $t_{12}$ & $t_{23}$ are fixed by the reaction times of the driver.

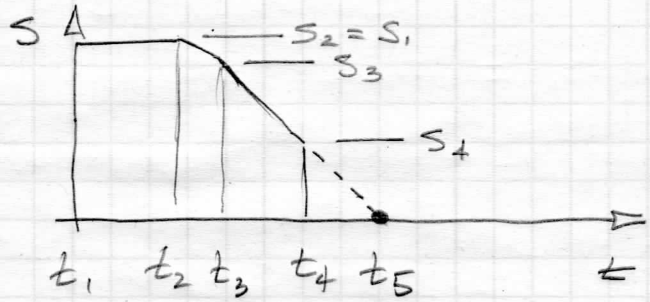
Since distance, d, is just the area under the s vs t curve, the distance to impact can be calculated from the area under the velocity curve, once $t_{34}$ is calculated.

Also the braking deceleration is fixed. It is the slope of segments $t_{23}$ & $t_{34}$. So with $t_{12}$ & $t_{23}$ fixed and the slopes fixed, to bring the car to a stop at $t_4$, this curve simply needs to be lowered overall by 27.0 mph. So the maximum speed to stop at the impact point is

$$S_2 - S_4 = 37.0 - 27.0 = 10 \text{ mph}$$

Hey, it was a parking lot. The driver shouldn't have been going 37 mph in a parking lot!

Another interesting question that can be answered by the above figures is what distance would have been needed to stop at the given $s_1$? If the $s_{34}$ curve is extended down to $s = 0$, this can be found.




For this we need $t_{34}$.

$$s_4 = a_{34} t_{34} + s_3 \,, \quad a_{34} = -fg$$

$$t_{34} = \frac{s_4 - s_3}{a_{34}} = \frac{s_4 - s_3}{-fg}$$

$$t_{34} = \frac{27.0 - 35.5}{-0.7 * 32.2} \, \frac{\cancel{mph}}{\cancel{ft/sec^2}} \, \frac{1.467 \, \cancel{ft/sec}}{\cancel{mph}} \, sec$$

$$t_{34} = 0.553 \ sec$$

By similar triangles.

$$\frac{s_3 - s_4}{t_4 - t_3} = \frac{s_3}{t_5 - t_3}$$

$$(s_3 - s_4)(t_5 - t_3) = s_3 (t_4 - t_3)$$

$$t_5 = \frac{s_3}{s_3 - s_4} (t_4 - t_3) + t_3$$

$$t_5 = \frac{35.5}{35.5 - 27.0} \, 0.553 \ sec + 1.2 \ sec$$

$$t_5 = 3.51 \ sec$$

Now these distances can be calculated.

$d_{14}$ is the distance from first perception to the impact point.

$$d_{14} = \left[37.0(1.0) + \frac{37.0+35.5}{2}(0.2) + \frac{35.5+27.0}{2}(0.553)\right] \cancel{\text{mph}}\ \cancel{\text{sec}} * \frac{1.467\ \text{ft}}{\cancel{\text{mph}}\ \cancel{\text{sec}}}$$

$$d_{14} = 90.27\ \text{ft}$$

distance to impact from 37.0 mph

$d_{15}$ is the distance needed to stop from 37.0 mph, given these reaction times of driver.

$$d_{15} = d_{14} + \frac{1}{2}\, 27.0\,(3.51 - \underbrace{1.753}_{t_4}) * 1.467$$

$$d_{15} = 125.06\ \text{ft}$$

Also interesting to note is where pedestrian was when the driver first perceived the danger. Assume pedestrian was walking at 2.5 mph. at $t_5$, 3.51 seconds prior to impact

$$d_{ped1} = 2.5\ \text{mph} * 3.51\ \text{sec} * 1.467\ \frac{\text{ft}}{\text{sec}}\ \frac{1}{\text{mph}}$$

$d_{ped1} = 12.87\ ft$

So at $t_1$