KILLER BEES 33

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Auburn Hills, Michigan

CG migration going over Bump with flat chassis (Multi-wheel or treads)

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CG Migration

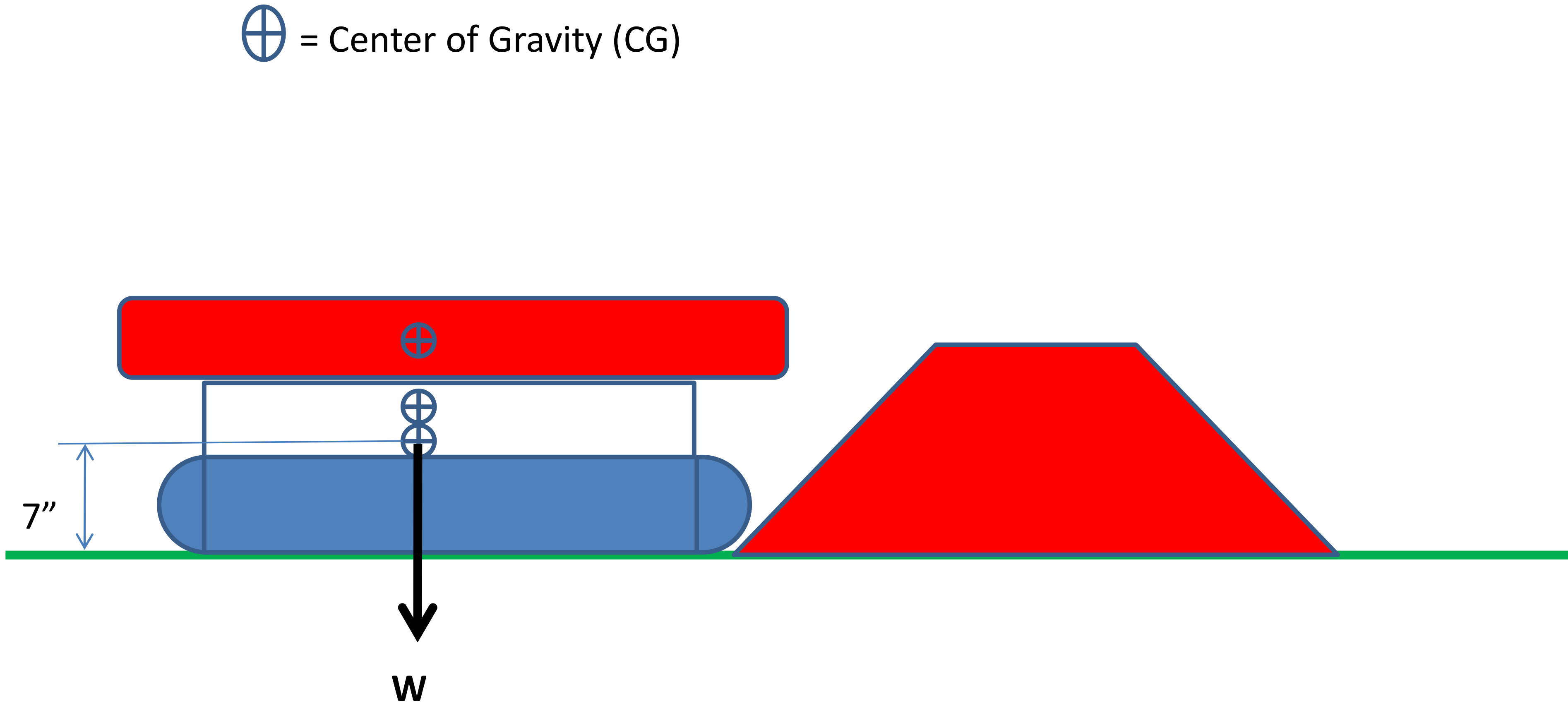
- CG or Center of gravity is an equivalent point of mass of a system relative to Gravity.
- Assume 20 Lbs of Bumper between 10-16” thus Center of Mass at 13 inches.
- Assume Various CG of complete Robot
- The following calculations show how the bumpers effect CG Height.
  - 120 lbs @ 6” + 20 lbs @ 13” = 140lbs @ 7”
  - 120 lbs @ 8” + 20 lbs @ 13” = 140lbs @ 8.7”
  - 80 lbs @ 8” + 20 lbs @ 13” = 100lbs @ 9”
  - 120 lbs @ 13” + 20 lbs @ 13” = 140lbs @ 13”

Assumptions

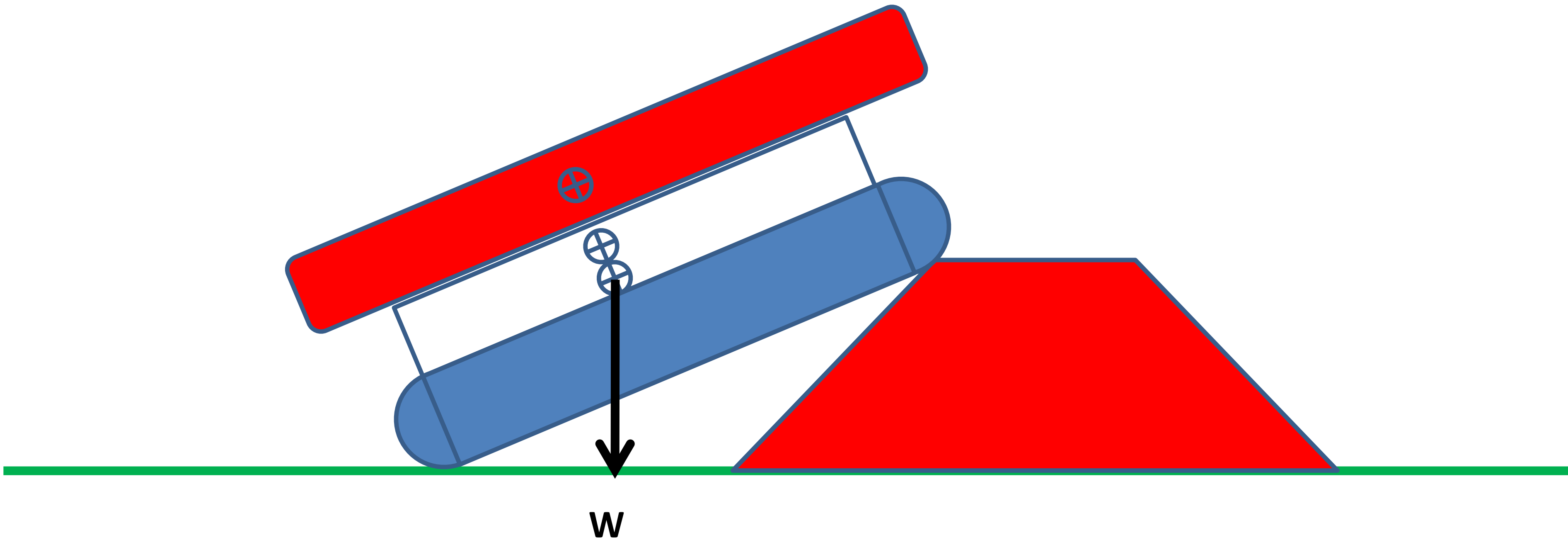
- Various Robot CG heights are assumed.
- CG is balanced for-aft in the machine
  - Most machines will be slightly forward or rearward.
  - Side to side is usually fairly centered for symmetric machines.
- These representations assume relatively slow accelerations and bump traversing speeds.
- Scale is roughly 10:1
  - 37” robot using 6” wheels/treads
  - 31” wheelbase.
- Graphics depicted are of fully supported track vehicles
  - Tracks will not likely be fully supported
  - Multi-wheeled (3+/side) will behave slightly different.

CG Migration of 7” High CG Biased 2” Rearward

120 lbs @ 6” + 20 lbs @ 13” = 140lbs @ 7”

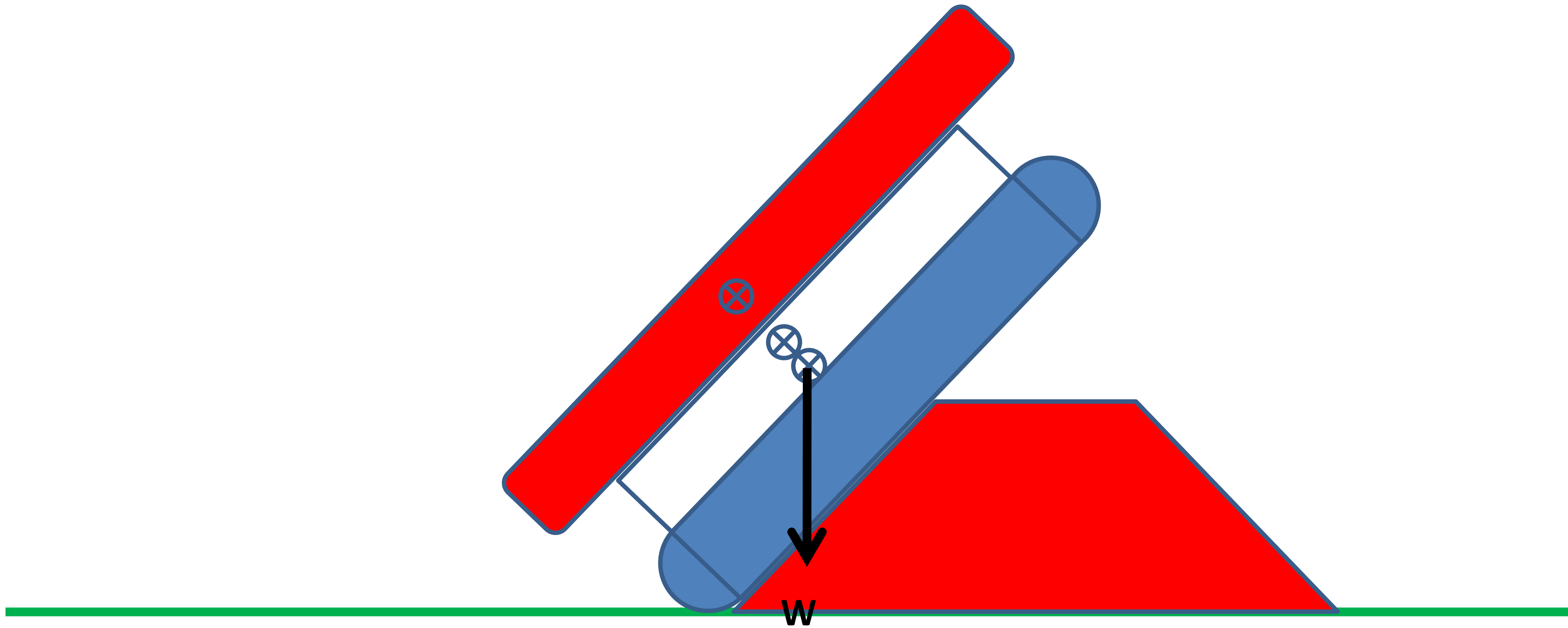


7” CG Approaching the bumps



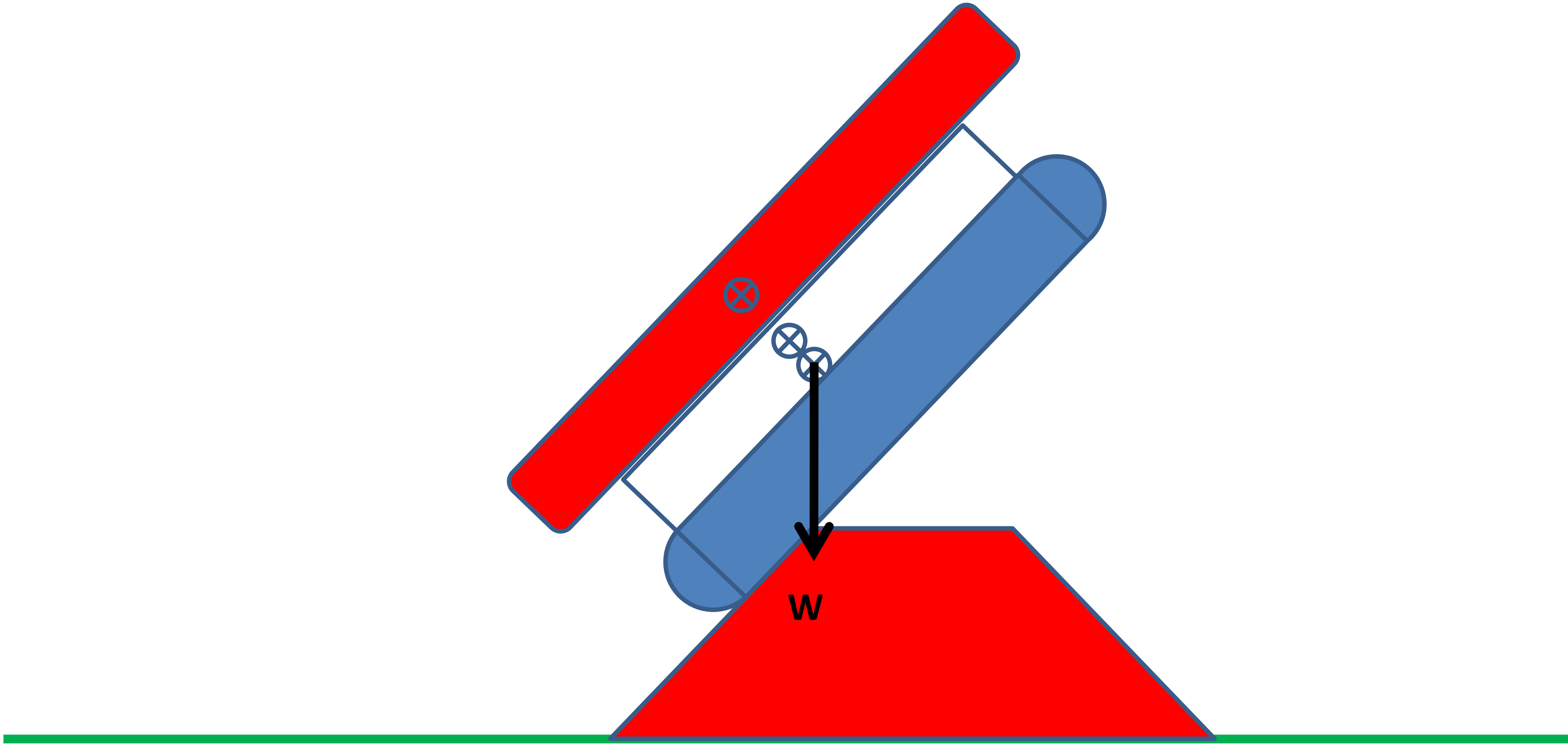
With a Flat Chassis the Robot will tend to initially climb with the front, and push with the back. As the angel increases, more of the weight is transferred to the rear wheel.

7” CG Hill climbing



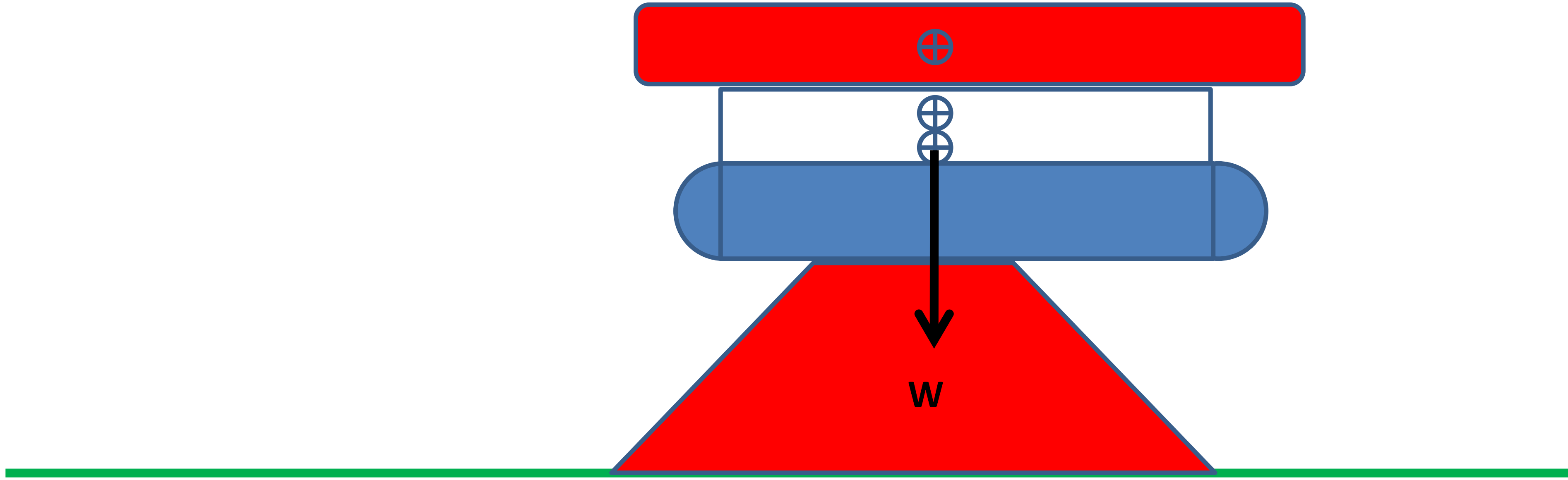
During the hill climbing portion, the Weight resultant stays within the wheel-base. A treaded design will continue to climb as long as the Weight is supported.

7" CG Cresting, Break-over-point



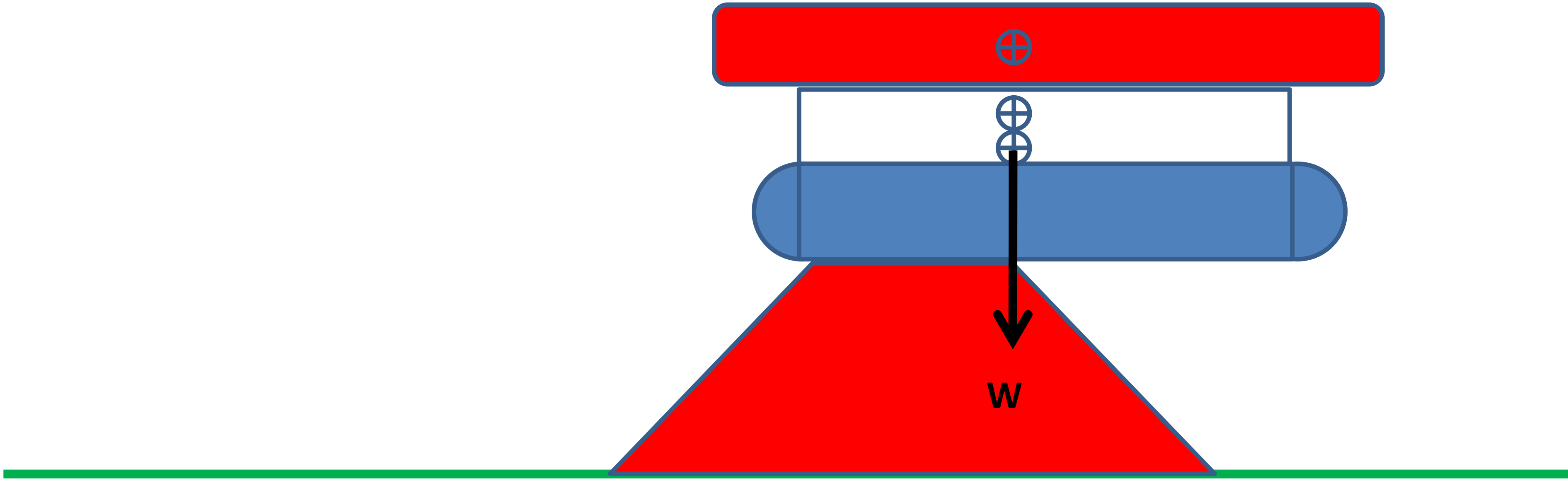
At the cresting point, the weight vector has aligned with the corner of the bump. Any additional forward movement will cause break-over. Note also that all of the robots weight may be on that edge.

7” CG Plateau Right after Cresting



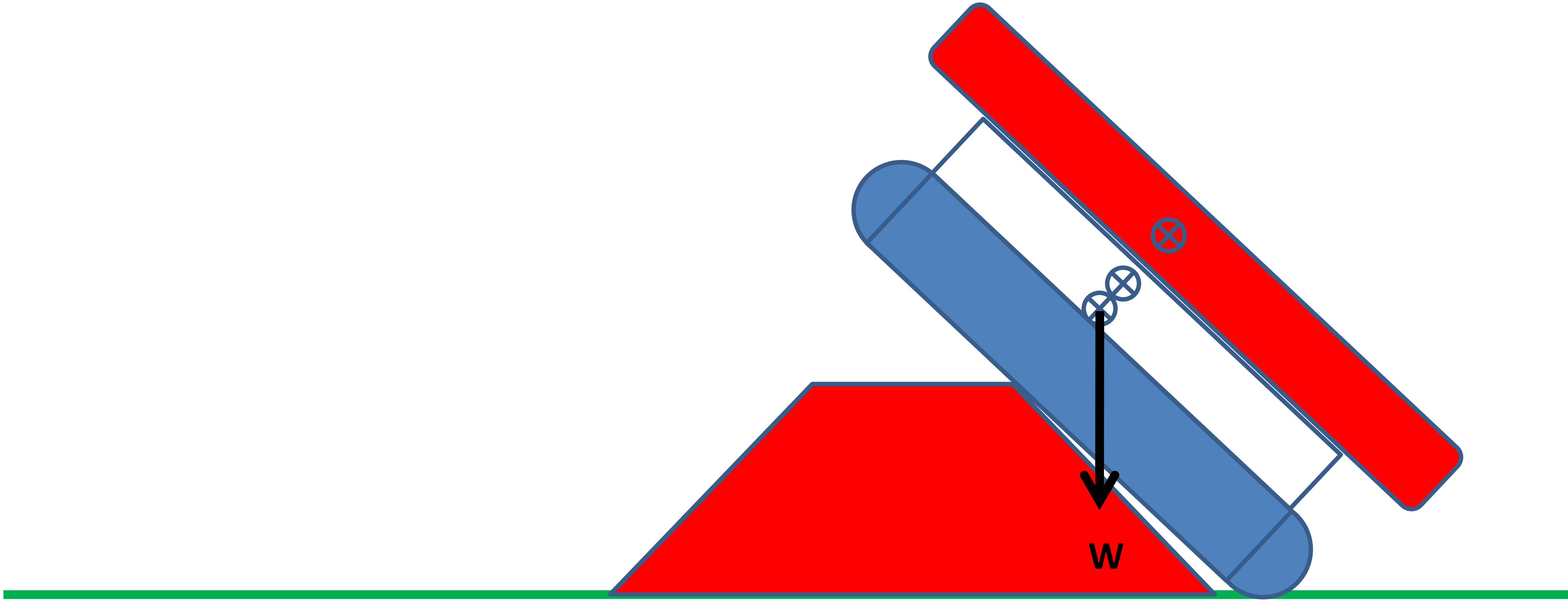
After break-over, the chassis will roll forward until the weight vector is supported. Note that even with a 7” high CG, the weight vector went from the leading corner to past the 50% mark of the plateau.

7” CG Breaking over final edge



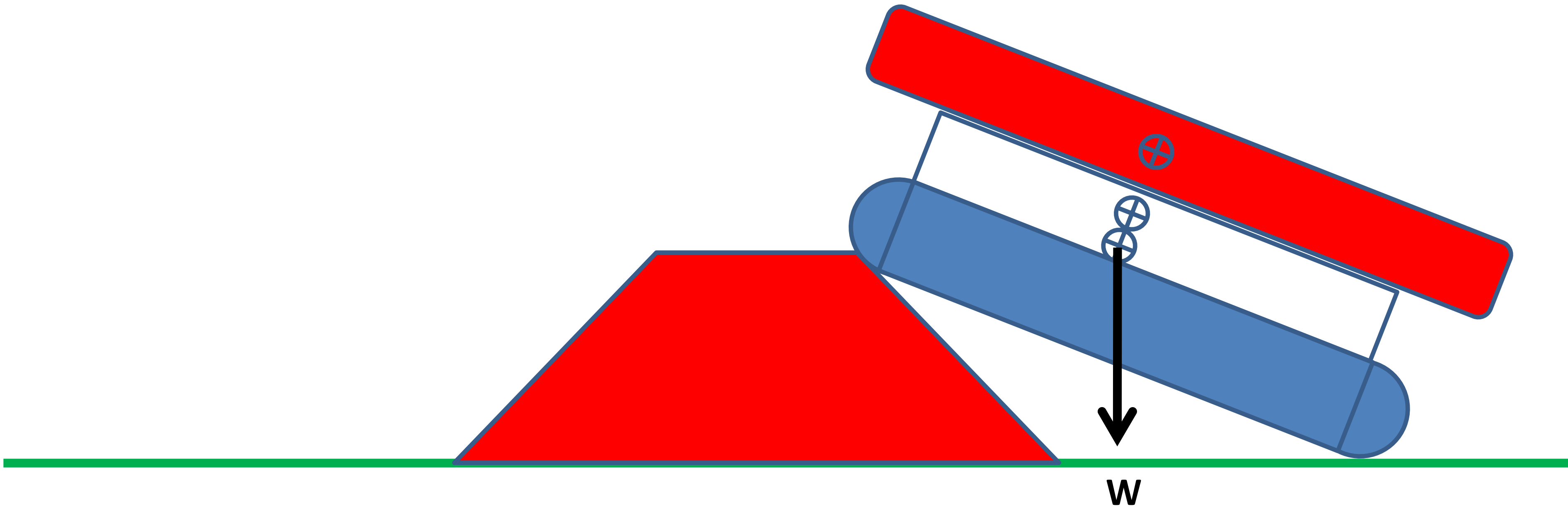
The robot should remain relatively flat until reaching the second edge. At this break-over point, it will want to roll forward again.

7” CG right after break-over.



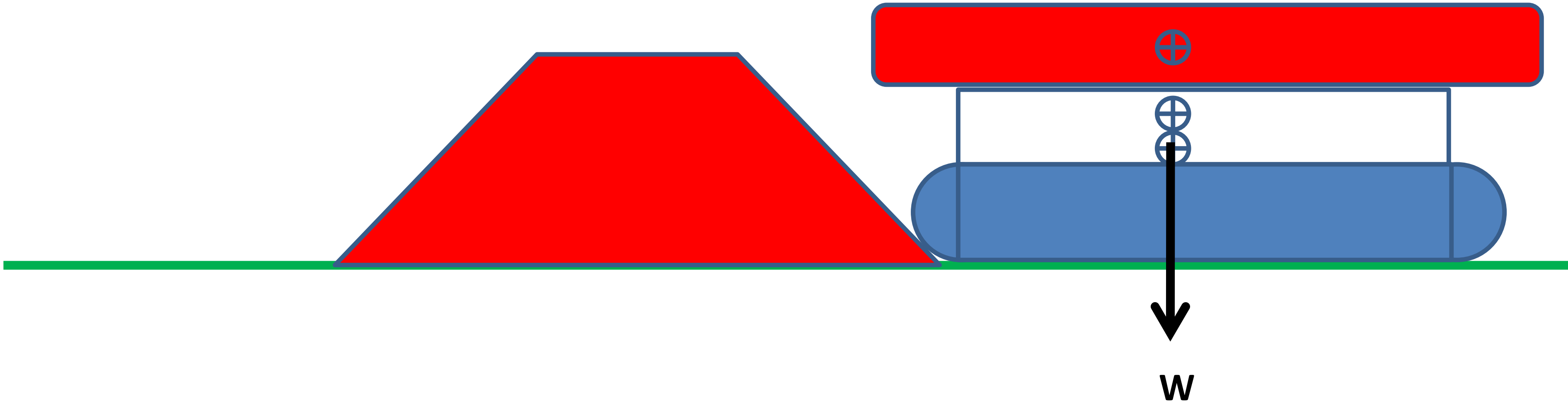
With this design, right after break-over, the CG migrates quite a bit forward, and the front wheels will impact the ground. This could be a pretty hard impact!

7” CG Descending.



As the robot descends, it will once again be supported by the front and rear wheels.

7” CG back on flat ground.



13” CG Track or Multi-wheel

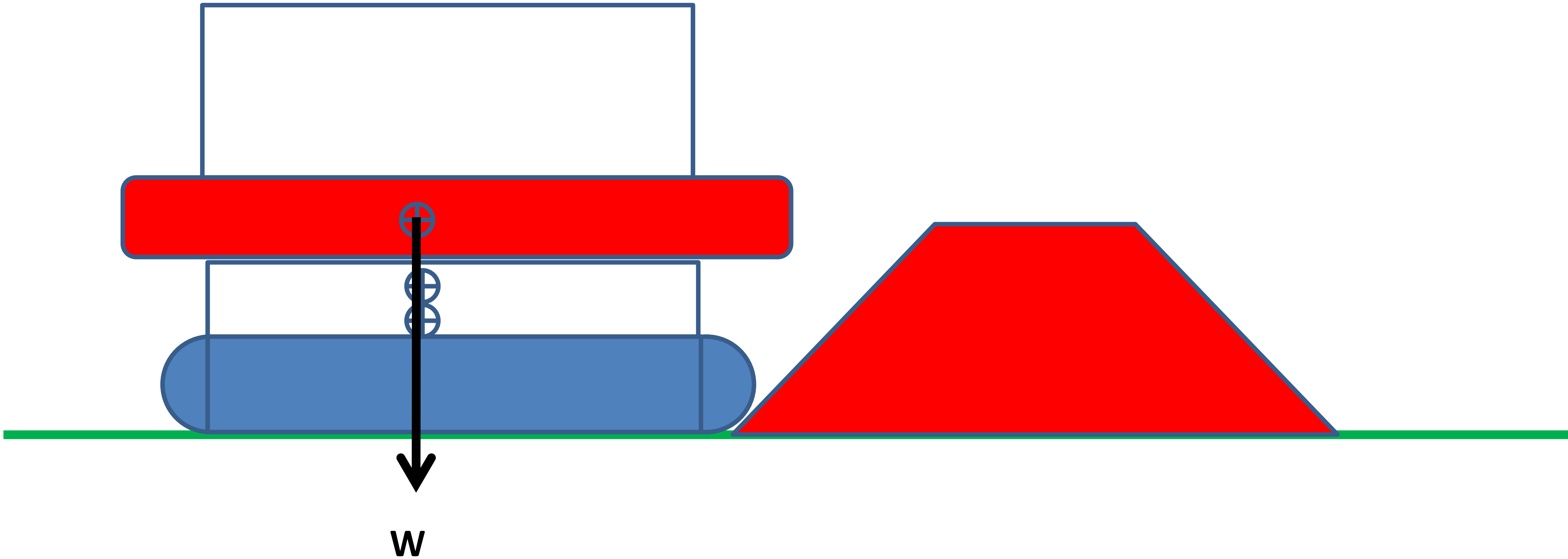
High (13”) CG Track/Multi-wheel

120 lbs @ 6” + 20 lbs @ 13” = 140lbs @ 7”

120 lbs @ 8” + 20 lbs @ 13” = 140lbs @ 8.7”

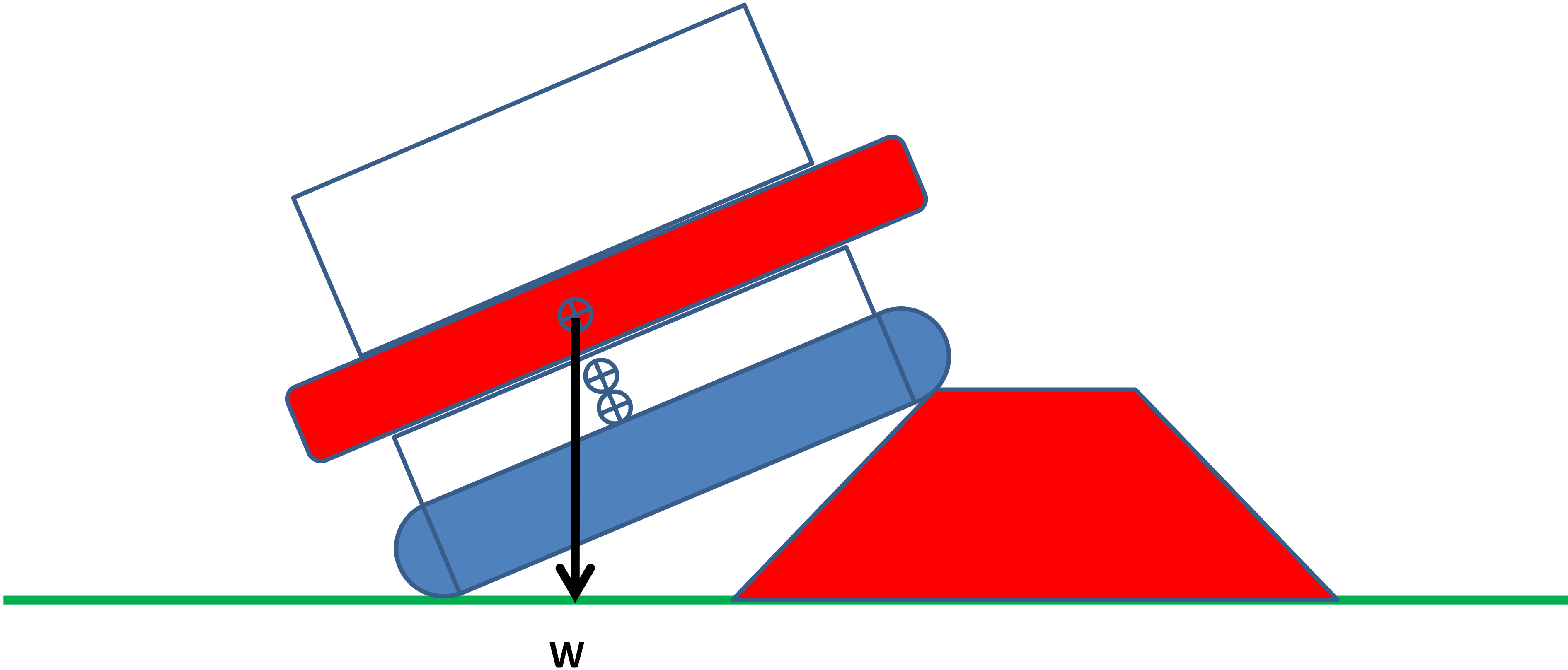
~~80 lbs @ 8” + 20 lbs @ 13” = 100lbs @ 9”~~

120 lbs @ 13” + 20 lbs @ 13” = 140lbs @ 13”



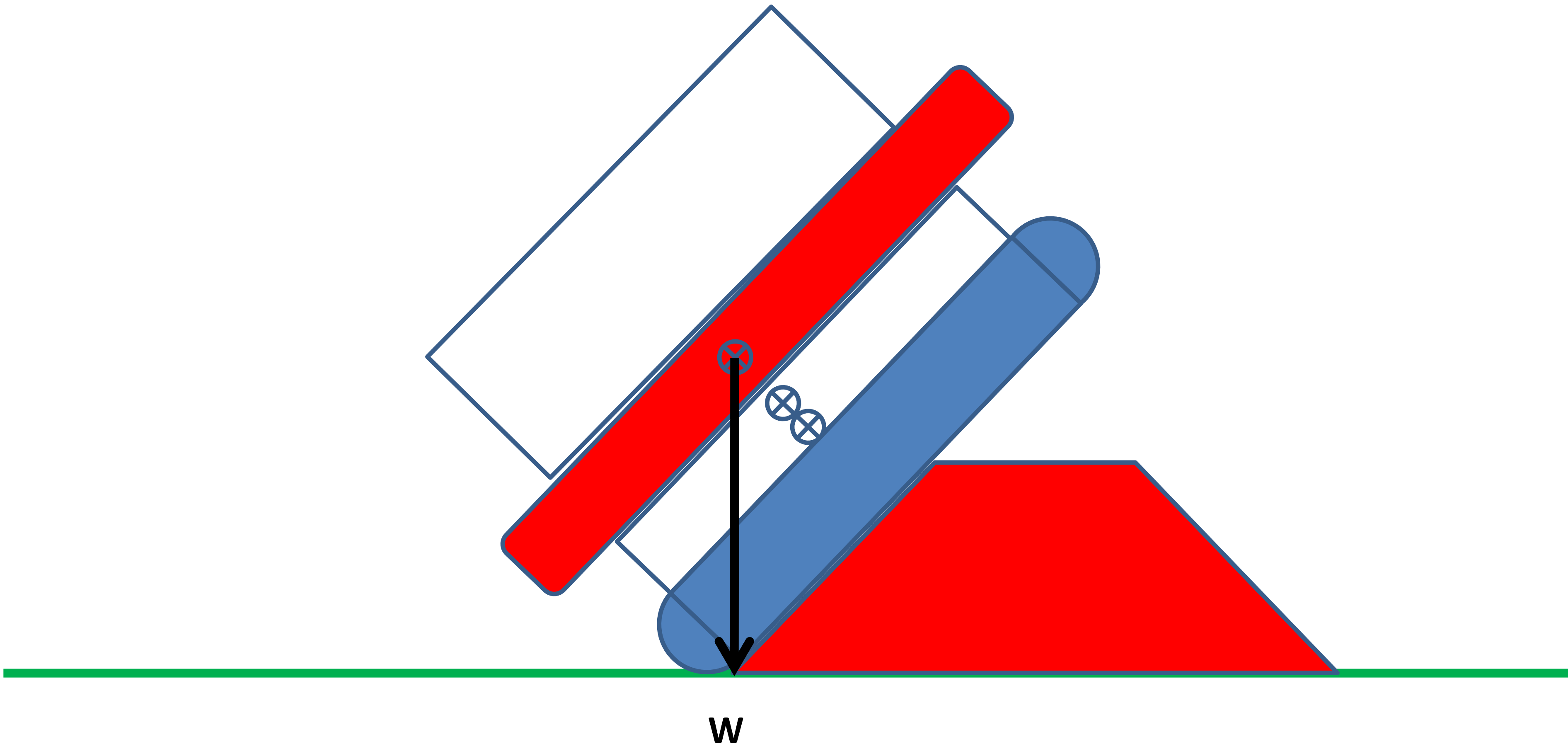
This Robot has some additional apparatus. On top (possibly for hanging). The added weight has pushed the CG up 6” to 13” (same as midpoint of the bumpers).

13” CG Approaching the bumps



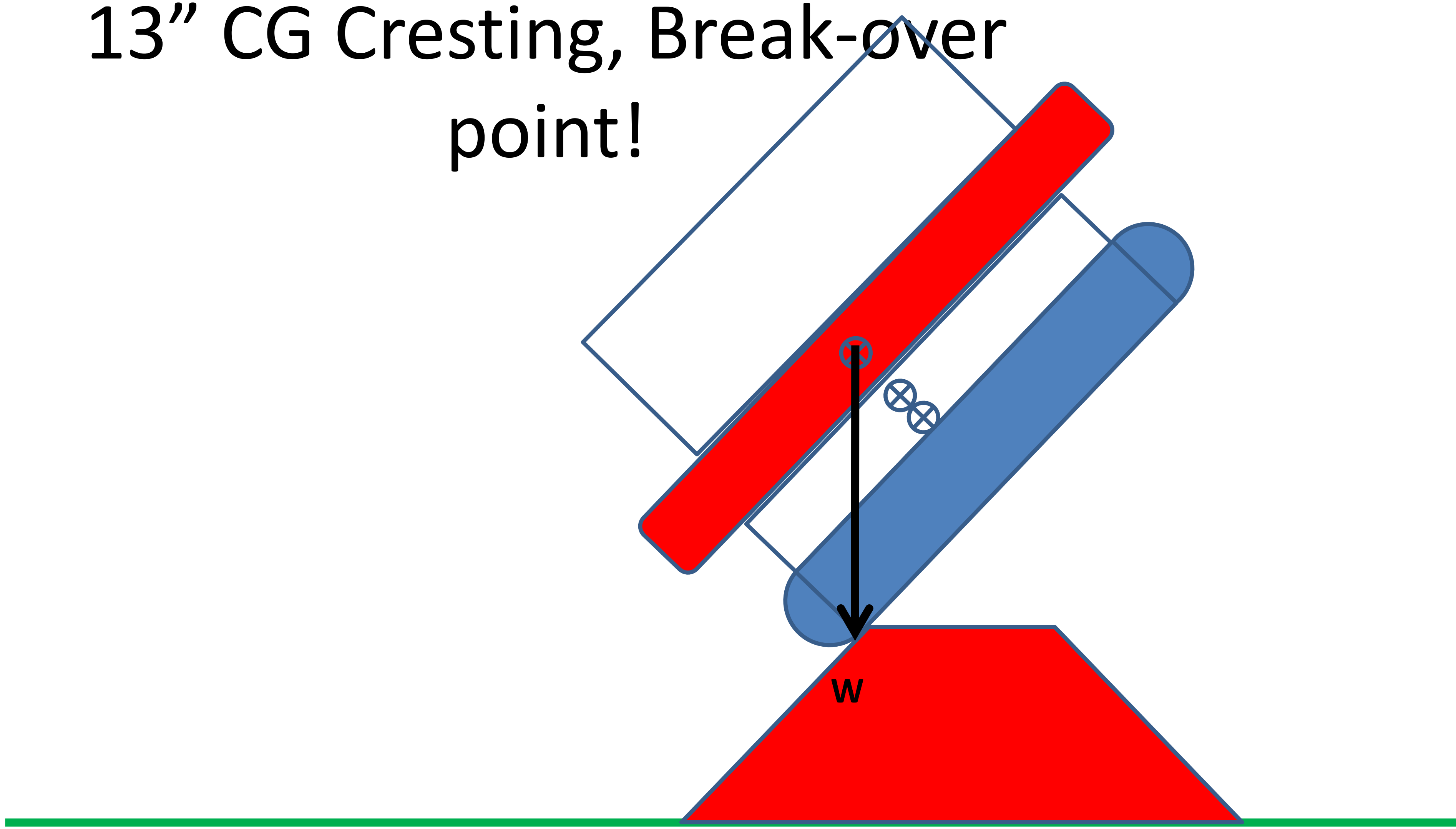
With a Flat Chassis the Robot will tend to initially climb with the front, and push with the back. As the angel increases, more of the weight is transferred to the rear wheel.

13” CG Hill-Climbing



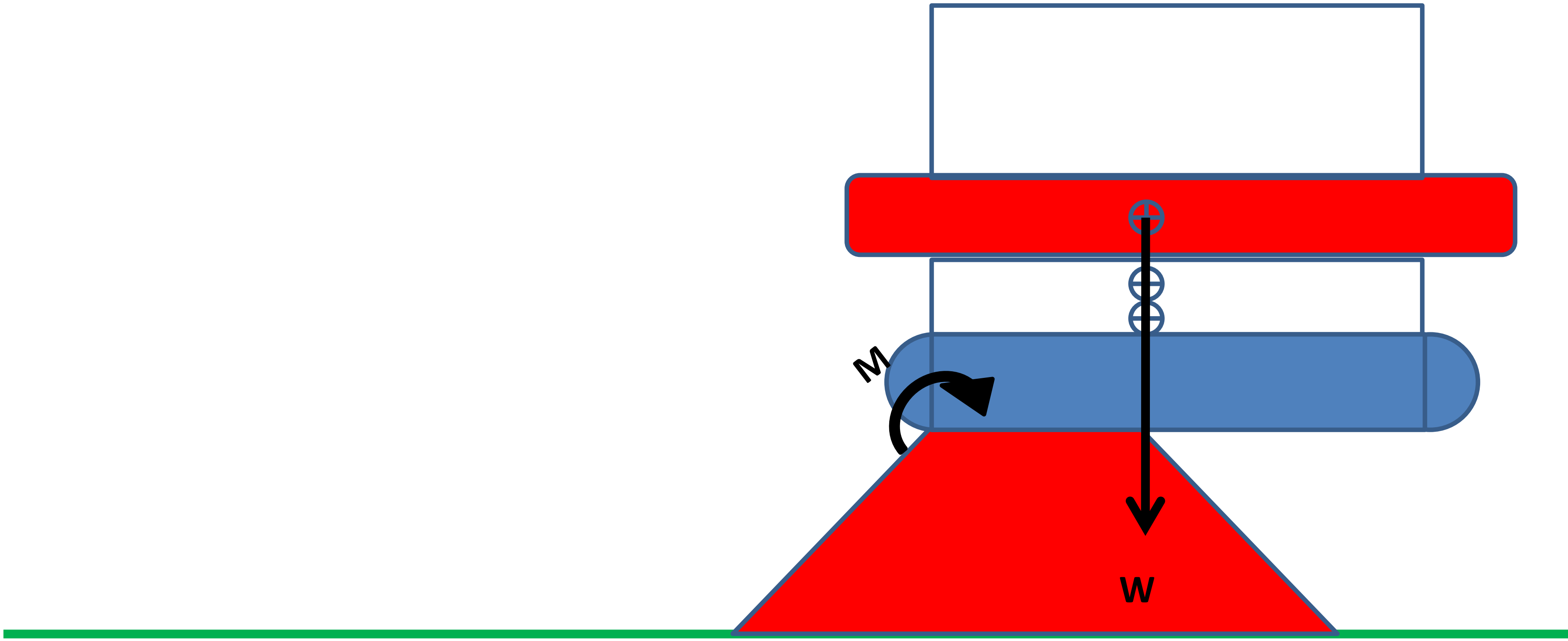
Due to the high CG, the CG migration during the hill climb has all the weight on the back. Accelerative forces and/or drive-wheel torque could cause this robot to flip over backwards.

13” CG Cresting, Break-over point!



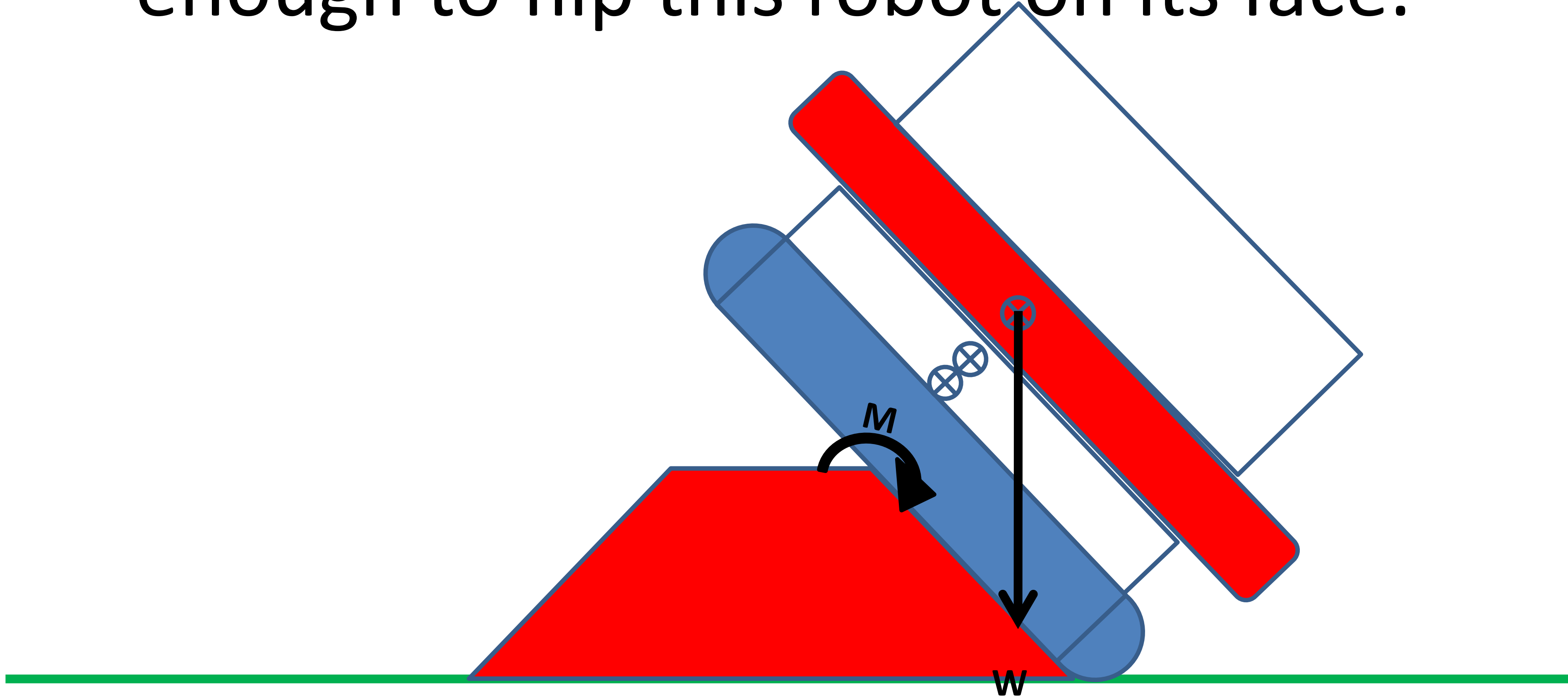
Since the robot won’t roll forward until the weight vector is unsupported, the robot will find itself in a very delicate balancing act at the breakover-point.

13” CG Plateau, Instant new Breakover point Momentum will keep it going



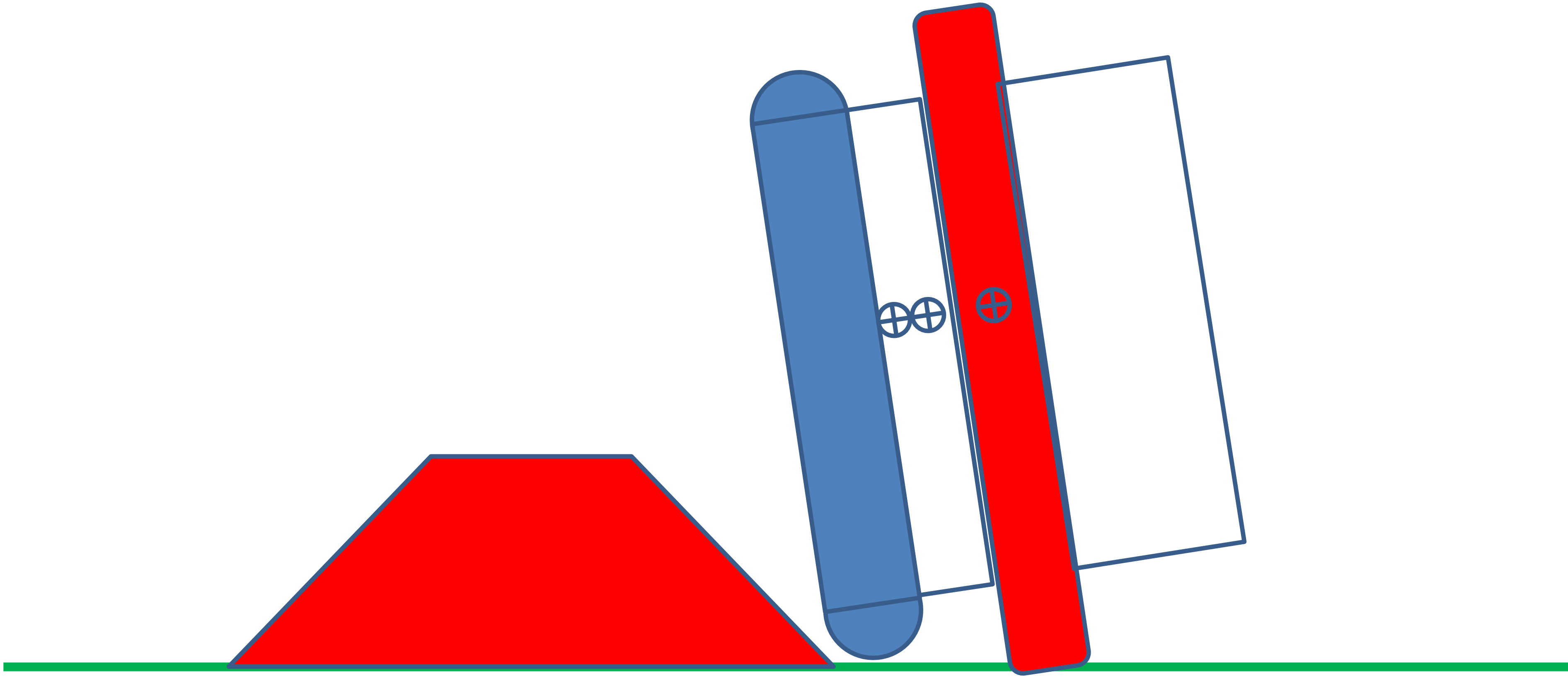
After break-over, the CG will migrate really far forward, in fact it will likely be right over the leading edge of the bump! With any momentum, it will continue to roll forward!

13” CG Landing. At this point the momentum of rolling over the hill may be enough to flip this robot on its face.



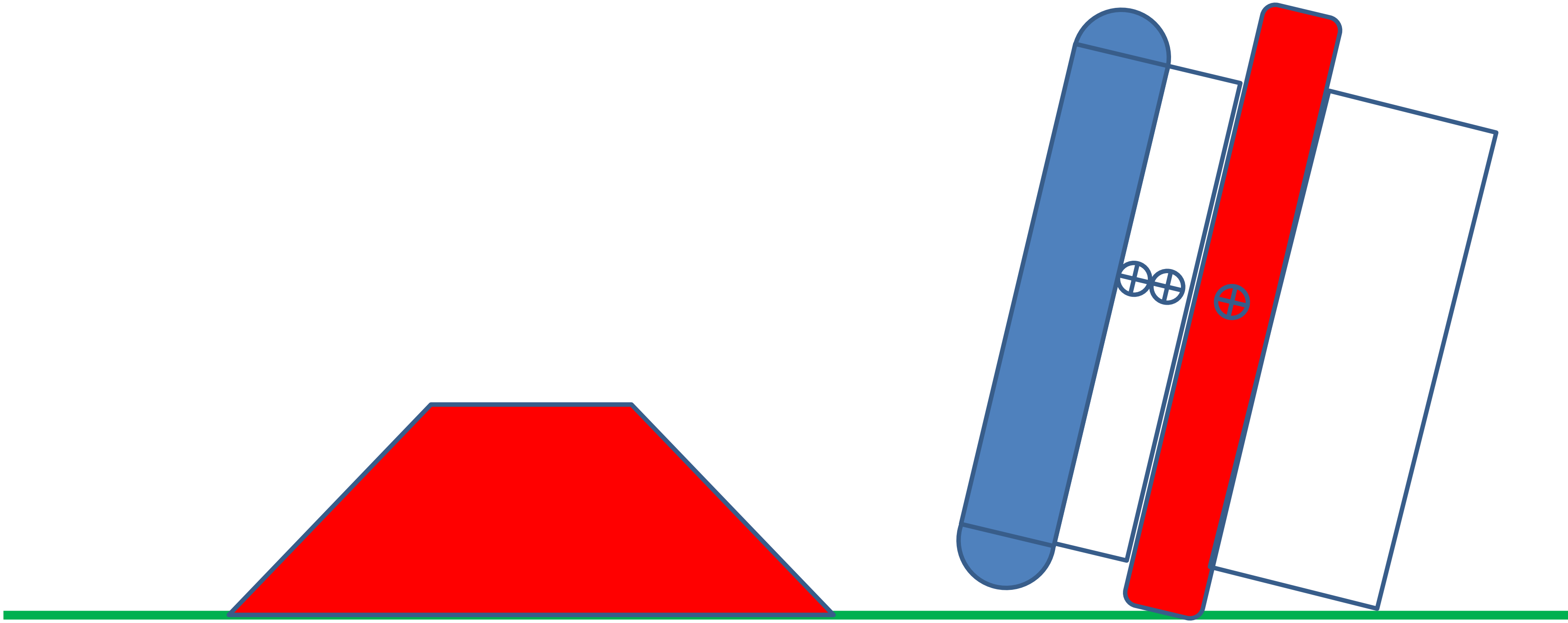
As the bot continues to roll, it will gain additional momentum! Even though the weight vector is supported in this picture, momentum will likely keep this bot rolling.

13” CG Continuing to flip



And Rolling.

13” CG Face-Plant



During this face-plant the bumpers will compress a bit. In this picture, the CG is over that point, so roll-back will not occur. Without assistance, this bots match is over.

Using Powerpoint As Tool

- 10:1 scaling is easy and fits well
- Use boxes and adjust "Size & Position" to use as both a measuring and placement tool
- "Group" and "Ungroup" components to move them into relative positions (and rotate assemblies).
- Use Ctrl+Arrow Keys for small adjustments.
- Use a CG point and a Weight Vector to follow CG Migration.
- Copy and paste slides at key points!

Estimating CG Height

- There is an excellent Paper on Chief Delphi by Mark Kramarczyk called “Weight budgeting tool”
- Without that, here are some simple estimating techniques.
- Approximate your base chassis weight (40-65 lbs) and place the CG height at axle height (3” for 6inch wheels, 4” for 8inch wheels…)
- Give the approximate height of the battery (12 lbs @ ? Inches)
- Give the approximate height of the controls (10 lbs @ ? Inches)
- Bumpers are 20 lbs at 13” (midpoint between 10&16”)
- Approximate Misc. Manipulators (20 lbs @ ? Inches)
- Add the weights and this is robot weight total: 65(chassis)+12 (battery)+10(controls)+20lbs(bumpers)+20 manipulators=127lbs total.
- Then multiply the weights by the CG heights, and sum those products: 65*4+12*8+10*10(assuming controls at 10”)+20*13+20*24(assuming manipulator centers about 24”)=1196 in*lbs
- Divide by robot weight 1196 in*lbs/127lbs=9.4” CG height
- This gives you a ball-park of where the CG height will end up.
- Since the actual inspection weight was 65+10+20=95 lbs, there is an opportunity to add ballast.
- Adding 25 lbs to the bottom (2” above ground) = (1196+25*2)/(127+25)=8.2 Inch CG height. This is a about 12% lower CG.
- The added mass will give you additional traction, but may slow down acceleration.