What Makes Space Traffic Different?

Why traffic lights and stop signs don't work in space.

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In a previous life, my job was to teach orbital mechanics to a wide variety of people, college graduates, high school graduates, technical and non-technical. It was a challenge because a lot of the "facts" that people have been told about space by Hollywood and the media is simply wrong.

The purpose of this brief is to boil down all the physics and technobabble into the real issues behind what makes space different from air, land, and sea and why traffic solutions that work in those regimes don't necessarily work in space.

Imagine...

...You are in a car travelling around the Beltway...

...A GPS unit shows your location and the roads...

...There are 500 other cars on the same roads...

...But there are no traffic signs, signals, or lanes...

...And your windows are blacked out so you can't see anything anyway (including the other cars)...

...Oh, and we are adding 50 cars a year to the roads.

This is the current traffic situation in space.

So why can't we just add stop signs and speed limits to space and call it good?

To begin, I would like everyone to take a minute and open your imagination. Imagine the following…

(read slide)

Would you feel safe driving to work like this every morning? If I were to tell you that the chances of getting in an accident were 1 in 100,000, would it make you feel any better? If this was the situation that all the policy makers had to deal with to get to work everyday, would they do something about it? Would the public demand for something to be done?

While traffic is not a new problem, the issue is that the tools we would use to solve a similar traffic problem on Earth don't necessarily apply to space.

Unique Properties of Space

1. Objects in orbit move ***very*** fast
2. Space is ***really*** big
3. Very few slowing forces

And that is because the space environment has three properties that make it unique.

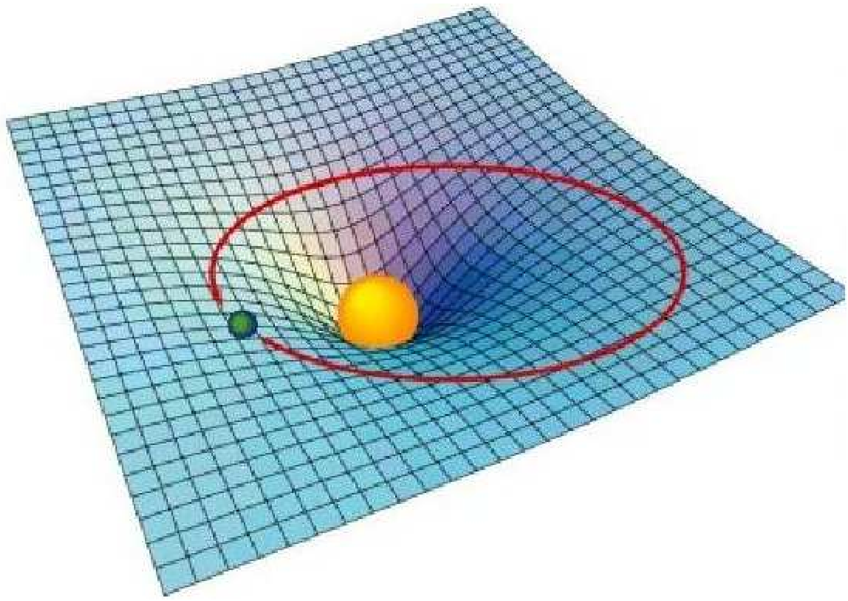
If you get nothing else out of this talk remember these three things:

-objects in space move very, very fast

-Space is really, really big

-And things don't slow down on their own in space

Mass Causes Gravity



The basic underlying physics are the fact that mass causes gravity. Think about a giant bedsheet being held up tightly along the edge by people so that it is a flat surface. If you drop a bowling ball into the middle, what will happen? The bowling ball will sink into the middle and cause a curve in the surface of the sheet.

The same thing happens with space and a large mass, such as the Earth. The Earth is causing the same sort of "depression" in space. We think of this depression as gravity because it pulls objects are pulled towards the center of the depression.

And just like the bedsheet and the bowling ball, the closer you get to the Earth the deeper the hole becomes and the stronger the pull is towards the Earth. In other words, objects are accelerated towards the center of the depression.

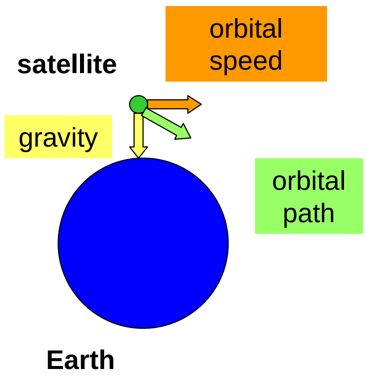
Gravity Causes Speed

So the mass of the earth causes gravity, or attraction towards the mass, and this attraction causes speed. If you have every been to a science museum and seen a funnel that you throw coins into (or watched water flowing down a drain), it is a similar effect. As the coins roll around the funnel they get faster and faster as they get closer to the bottom.

(play video)

This same concept happens with gravity and objects in orbit – the closer they are to the Earth, the stronger the pull of gravity and the faster they need to move to avoid getting sucked down the funnel (or in this case into the atmosphere).

The Myth of “Zero Gravity”



- Gravity exists in space and extends to infinity from the Earth
- Objects in orbit are pulled towards the Earth by gravity but miss because of their orbital speed (i.e. “freefall”)
- Space booster performs two functions:
  - Lifts payload to appropriate height
  - Accelerates payload to the speed needed to maintain orbit at that height (~ 17,000 mph at 196 miles)

The shocker to most people is that there is no zero-gravity. Gravity exists in space. Every object in the universe that has mass exerts a gravitational attraction the extends out around it.

The Earth attracts satellites towards it. Satellites then have to move forward at a very fast speed so that they “miss” the Earth as they are falling. This is called “free-fall”. And when you combine their fall towards the Earth with their forward speed you end up with an orbit.

This is why satellites cannot realistically “hover” in one spot over the Earth – gravity would pull them crashing back down. They must move forwards at incredible speed to avoid getting pulled back to Earth. And a rocket that is trying to put an object into space must accomplish two functions: lift the satellite to a specific altitude and give it the forward speed it needs to maintain that altitude.

Now that we know why satellites have to move so fast, lets look at the next property of space – size.

Space is Big

- Volume of oceans (avg depth 2 miles)

  400 million cubic miles

- Volume of atmosphere (sea level to 60 miles)

  12 billion cubic miles

- Volume of space out to GEO belt (21,472 miles)

  70 trillion cubic miles

When we start talking about how big space is, the numbers are so mind-bogglingly huge that I think the best way is to try and compare it to things here on Earth.

If we take that average depth of the ocean of 2 miles, that gives us somewhere around 400 million cubic miles of volume.

If we assume that the atmosphere exists from sea level to 60 miles of altitude, that means it has a volume of somewhere around 12 billion cubic miles.

Those are pretty big numbers. So let's now try and look at space. Let's assume that space starts at 60 miles above Earth and continues out to the geosynchronous belt where most communications satellites are. That's 21,472 miles away. And this gives a volume of a whopping 70 trillion cubic miles. That's five and a half thousand times bigger than the atmosphere and oceans put together.

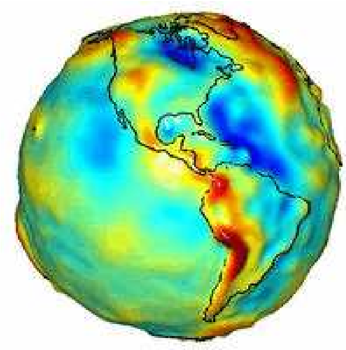
So if you every hear someone talking about observing all of space and tracking everything, they are either lying or don't really know what they are talking about. Because space is many times bigger than the atmosphere and oceans combined, and we humans don't even claim to be able to watch those at all times.

Objects in orbit don't slow down

- On Earth, friction and drag slow things down
  - No friction in space
  - Drag in space very reduced and only affects satellites < 600 miles
- In space the forces change an orbit but don't slow it down very much

Earth's Gravity Field

(via GRACE satellite mapping)

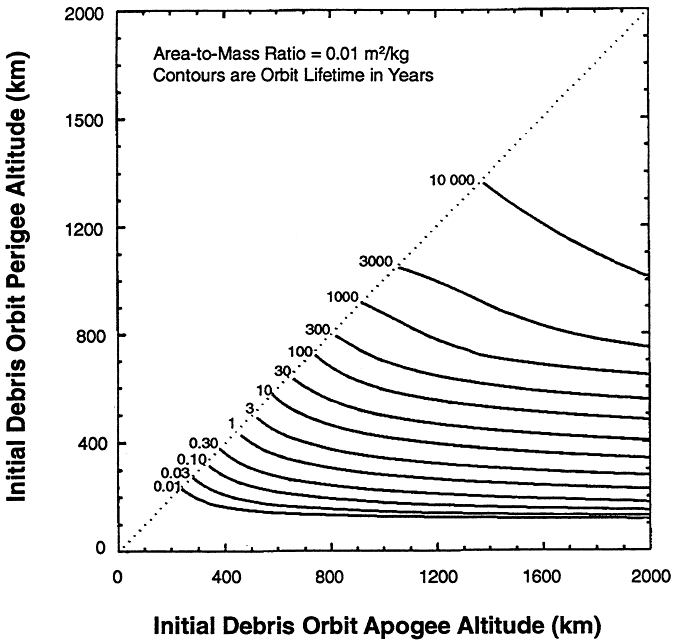


Our experience on Earth is that objects in motion usually slow down and come to a stop all by themselves as a result of friction. We have to work hard to keep things moving. In space, it is the reverse. There is no friction in space because there is not a surface that an object is pressing against. Yes, the atmosphere does exert drag on satellites but only to an altitude of 600 miles or so.

The forces that do act on satellites tend to change the direction of their velocity but are usually conservative in terms of energy. The biggest outside force acting on satellites is the mass asymmetry of the Earth.

The Earth is not a perfect sphere. It is flattened at the poles and bulges around the middle (sound familiar?) And because the mass of the Earth is what causes gravity, this assymetry means that it's gravity field isn't the same everywhere. This picture shows the areas of greater (red) and weaker (blue) gravitational pull. As satellites fly over this change in gravity affects their orbit by changing their position while their forward speed remains constant (for the most part).

Lifetime in orbit vs Altitude



The lack of slowing forces means that objects that are placed in orbit tend to stay they for a very long time. This graph shows lifetime in orbit as a function of altitude. The International Space Station orbits at an altitude of around 220 miles (350 km) and if it wasn't boosted periodically it would re-enter within a few months. Most imaging satellites orbit at around 500 miles (800 km) and without boosting would stay on orbit a couple hundred years. Above 600 miles where the atmosphere no longer exerts drag, objects will stay in orbit for thousands of years. Essentially, forever in human terms.

So the three major properties we have discussed: the speed of satellites, the immense siz

(Read slide)

So what happens when one of these fast moving objects connects with another fast movin

½" BB into a solid metal block at 4.3 miles/sec

This is a hypervelocity impact test that was done by NASA. A 1/2 " metal BB was fired into a block of solid aluminum at 4.3 miles/sec, which is actually a bit slower than the Shuttle or Space Station travels. The end result was the massive hole you see above.

Orbital Population

- Trackable objects (greater than 4 inches)

  20,000

- Untrackable objects (½" to 4 inches)

  300,000

- Tiny particles (less than ½")

  20 billion (guesstimate)

How many of these objects are in space you ask? Well that depends on what size you are talking about. If you are talking about objects that we can track with currently available means, which is about 4 inches or larger, there are around 20,000. If you talk about objects down to ½" like that metal BB on the previous slide, we estimate there are around 300,000. And if you go down to grains of sands we guesstimate around 20 billion give or take a few billion.

Thankfully, space is big (we talked about that) so the odds of two or more of these objects coming into contact with each other is around 1 in 100,000 on average. But that is for all of space. It turns out that a lot of our satellites are packed into the smaller regions, such as the GEO belt or Sun-synchronous orbit. In those areas the risk of collision is approaching 1 in 10,000 or higher.

So space is big, there is lots of stuff, and stuff moves fast.

Why is it an important issue for policy makers?

Your takeaway from this talk should be that space is big, there is a lot of stuff, and stuff moves really, really fast. The question now becomes, why is this an important issue for policy makers and what can be done about it?

For that I will introduce my colleague, Ben Baseley-Walker.