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Keynote Speaker: TS Kelso, A Personal Journey

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STM: A Personal Journey

It seems to be common wisdom that you can't get where you're going without knowing where you've been. In researching this quote, it doesn't appear to be attributed to any one philosopher in particular, and some suggest that it is a variation on George Santayana's quote that those unaware of history are destined to repeat it.

Regardless of the source, we have all experienced occasions where we realized the value of experience—whether it be ours individually or learning from others—in reaching our destination or at least in charting a successful journey.

I think the same is true for Space Traffic Management. We have heard many speakers present concepts this week on what STM as a destination should look like. And it is important to clearly articulate the characteristics of that destination, so that we might recognize it when we get there. But there is also value in understanding how we got to where we are and what that might tell us about how to get to our ultimate destination.

So, I'm going to take a different approach to this keynote than most of you might expect. Many of you know me—some for many years—and realize that I am an analyst at heart. Give me data and a question and I will work to determine what the data tells us. It's not my story, it's the data's story. But today I'm going to take you along on some of my journey and—as we say in the islands—talk story.

My journey started with an awareness of the consequences of losing key satellite communications assets in the early days after the September 11th attacks. I had just taken over leadership of the AFSPC Space Analysis Center working for Gen Eberhardt and Gen DeKok less than two weeks before the attacks and soon found myself in the position of being responsible for all space-related analysis for the US Air Force.

It wasn't long before we were conducting military operations in both Iraq and Afghanistan and relying heavily on satellite communications for a variety of missions in those theaters. Unfortunately, there were not enough dedicated military communications satellites to meet the need and pretty quickly we were depending on our commercial partners to provide 80-90% of all communications to these theaters.

While our comm specialists were working hard to protect these satellites from a variety of threats—such as jamming—I realized nobody was doing anything to ensure we didn't inadvertently run two of these satellites into each other and cause a catastrophe in GEO.

Many seemed to rely on the 'big sky' theory that space was a big place and that the chances of a collision were miniscule. Others seemed to think that someone—notionally the US military—was already keeping an eye out for such situations and that they would be notified in the event of a serious close approach. The only reason they had never been contacted must be because there had never been a need.

To ensure I fully understood the situation, I called a meeting of key players at HQ AFSPC. I began by asking the major from CMOC what they would do if two military communications satellites got too close. He told me that both operators would be contacted, advised of the situation, and they would work together to determine who would take whatever action was necessary.

I then asked what would happen if a military satellite was predicted to get too close to a commercial satellite. I was told that the military operator would be informed and they would take whatever action was required. There was (apparently) no need to contact the commercial operator.

Finally, I asked what would happen if two commercial satellites were predicted to get too close. I was told that no such screenings were performed because "we have no requirement." I asked if the fact that more than 80% of our comm going into two major theaters might be using those satellites would make a difference. "Sir, we have no requirement." I then pointed out that if those two satellites collided, they would produce debris that would drift around the GEO belt basically forever, risking all of the comm satellites we depended upon and asked if that changed his answer. "Sir, we have no requirement." I *really* hated that answer.

The questions weren't really intended for the major—who was intimately familiar with operations in CMOC—but for the senior staff sitting around the room. Unfortunately, most of them seemed content that the major had absolved them from having to do anything—because there was no requirement.

Not content to simply drop the problem, I talked with a number of people that might be able to help develop and implement some type of solution. After all, the lives of American service members were ultimately at risk. I was told that any solution would require a supercomputer, would cost millions of dollars, and likely couldn't produce and distribute results on a time-scale that would be operationally usable. These assertions proved impossible to disprove in any meaningful way without actually doing something—much to my dismay.

Soon I found myself on a different path. Toward the end of 2003, AGI asked me to come work for them as part of their new CSSI. When I asked what I was supposed to do, I was told by our CEO, Paul Graziani: Just go do something good for the community. How refreshing! It didn't take long for me to decide what I wanted to do—to address the conjunction analysis problem.

I had a vision of where I wanted to go and it started with first showing the art of the possible and then identifying the shortcomings and developing solutions to address them…in true analytical fashion.

The first step was to disprove the assertions about why we couldn't do anything. I wanted to show that we could implement a low-cost, effective solution using standard data products and COTS hardware and software. The goal was to use a standard desktop computer (circa 2004), two-line element set data for the orbital data, and a customized application built on STK.

Before I could actually implement the solution, however, I managed to break both my radius and ulna in my left arm on a training ride cycling in the Garden of the Gods. I found myself with my arm in a sling and on major pain medication. Still, I was able to code the STK application, set up the process to automate generation of the data, and then have it push the results out to CelesTrak as the SOCRATES service—Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space—and do all of that within two weeks.

The solution cost next to nothing—a standard desktop computer and an STK license—and could produce results screening all payloads (~2,600) against the entire public catalog (~8,300) in about 90 minutes. Effectively, I had done that with one arm tied behind my back and on some serious drugs. And we all know that retired colonels are not the sharpest tools in the shed. So much for why we couldn't do anything.

The next step was to show that the data—the two-line element sets or TLEs—really weren't up to the task. It wasn't that TLEs were bad, just that they were designed to do something else—to allow 'fast' computation of orbits to sufficient accuracy to maintain track custody of objects in space. But typical accuracy for LEO objects was 2-3 km and for GEO was more like 20-30 km.

That was more than adequate for a sensor to find an object—if it hadn't maneuvered—but predicting a 100-m close approach with an uncertainty of ±5 km wasn't really actionable information. The bottom line was that it wasn't hard to demonstrate the accuracy limitation using a number of objects in reference orbits, but the goal wasn't to simply find the problems but to identify and implement solutions.

So, we started with the hardest part of the problem first. It turns out that the toughest objects to track are the ones that maneuver. Small maneuvers can take days for the Joint Space Operations Center (JSpOC) to detect and process. In the meantime, observations are collected and processed assuming all the forces acting upon the satellite are known. That results in bad orbits with growing errors.

Large maneuvers can be even worse, because a satellite might diverge from its original orbit so quickly between sensor observations that it no longer appears to be the same object. That requires additional (manual) analysis to determine that a maneuver might have occurred and then try to associate it with a known object—or determine whether it is a new object.

And, of course, there was no way to know about planned (future) maneuvers, which would dramatically alter the circumstances of any predicted close approach. Or was there? If only there were someone to ask… As it turns out, all maneuvering satellites are controlled by operators who know when and how they will maneuver.

SOCRATES had been designed functionally to allow incremental improvements in the data. Obviously, if TLE data got better, so would the conjunction analysis. But what if we just asked satellite operators to send us their ephemeris that they already produced as part of their flight dynamics process? We would know about their planned maneuvers as soon as they were incorporated and would get updated orbit determination results as soon as post-maneuver observations were processed.

So, I started with Iridium in July of 2007, since I knew a number of the flight dynamics personnel there. But we never got far because their support contractor insisted their orbital ephemeris data was ITAR-protected. This was an omen of one of the key problems we face even today—the need for transparency and sharing to ensure that everyone has the same picture of the situation to minimize the chance of conflicting analysis producing bad results. We'll talk more on this later.

Then, Intelsat contacted me and asked if we could use their ephemeris in place of the TLEs in SOCRATES. Somebody else got it!

We started by getting sample ephemeris data from Intelsat and making sure we knew how to correctly interpret it. While having a standard data product was preferable, each operator was tied to a set of legacy hardware and software that limited their flexibility. We wanted to set up a data flow that received the original data product and then converted it into a standard data product for analysis. That meant understanding the coordinate frame, time system, units, and format of the data.

The next step was validation to ensure that understanding. As it turned out, our results did not match, even though we were using what we thought was the same coordinate frame. Once I asked Intelsat to define their coordinate frame, though, it became clear that our terminology did not match. Adjusting the coordinate frame fixed the problem and reinforced the need for the initial validation.

And recurring validation has proven to be key to producing dependable results, because systems can get out of whack for a variety of reasons—whether that's for a single satellite or an entire fleet. And we regularly find and report errors in the JSpOC data as part of that process, too, to help ensure the best overall SSA picture for the community.

After spending some time refining and testing the process and making it adaptable to different operators, Intelsat hosted a meeting in January 2008 to advocate our new SOCRATES-GEO service, since they realized that knowing only the position of their satellites was not going to be enough. SES and Inmarsat had already agreed to participate and Telesat attended to play devil's advocate.

Actually, Telesat raised a number of good questions that helped us improve our service and by December 2008, Telesat had joined and hosted the next meeting with a much larger attendance. We were getting strong interest from operators around the world for the need to work together to come up with a solution.

In February 2009, the dynamics and urgency changed when IRIDIUM 33 and COSMOS 2251 collided in LEO, producing what would ultimately be determined to be thousands of pieces of debris 10 cm or larger. JSpOC was unprepared to deal with the sudden demand to do something and held a meeting in May to explain all the reasons they couldn't.

That was unfortunate, since I had visited JSpOC in August 2008 to offer to tailor a version of SOCRATES to work with their SP data—at no cost to the US government, since it was considered by AGI as maintenance under their existing license of STK. JSpOC politely declined the offer. The outcome of the May meeting was that now the LEO community was interested in developing a SOCRATES-LEO service, as well.

As a result of the collision, there was a more widespread appreciation of the risks of inadvertent collisions in Earth orbit and the potential consequences for current and future space operations. Satellite operators, in particular, understood the need to work together to do something now instead of waiting for someone to implement regulations or laws that could potentially make an efficient, collaborative solution more difficult.

Thus, the Space Data Association (SDA) was born and now counts 30 satellite operators from almost as many countries—including commercial, civil, and military entities—as members. The SDA contracted with AGI to create the Space Data Center (SDC) to perform conjunction analysis, data validation, and value-added analysis of JSpOC products to ensure safety of flight. The SDC screens over 700 of the almost 2,000 operational satellites in Earth orbit 24/7 using data from SDA members and the JSpOC. All processes are fully automated and standard data products are provided via web services in a secure environment.

One might think we had already reached the end of our journey. But let's take a moment to consider our path. Because there are similarities in what we might need to travel safely and what we need to do to ensure safety of flight in space.

Let's assume we're driving along our path doing some space trucking. We see other vehicles (cars, trucks, mopeds) along our path that might pose a safety risk. What might I need to know to minimize that risk? For starters, I'd like to be able predict where the other vehicles might be in the future. Motor vehicles, like satellites, obey certain 'forces'. One of those 'forces' is that we expect the vehicle to stay on the road and that they are traveling at or near the speed limit.

If I knew the positions of the other vehicles and their velocities, I could predict where those vehicles will be in the future—and that day is coming. And then I would know which vehicles might be close to me at some point—even the ones in crossing traffic.

But what about the uncertainty of that estimate? Even without precise position and velocity today, if I'm confident the other driver is in their lane and I'm in mine, we regularly pass closely—often at high speed—without a problem. But if all I know is that we're both on the same road, deciding whether a corrective action is needed and whether I need to veer left or right becomes much more difficult.

And what about knowing whether the other driver wants to turn? Knowing they are going to turn away from our path before we get there might eliminate what otherwise seemed a problem. And turning across our path without our knowing could have serious consequences.

What else might I need to know? What about the consequences of misjudging a close approach? If I'm driving a tractor-trailer and misjudge a close approach with someone on a moped, I might not be too concerned… although I'm pretty sure the moped driver would feel differently! But if I misjudge a close approach with another tractor-trailer, we could both be killed and the traffic could be indefinitely impacted (remember, there are currently no tow trucks in space).

Basically, we need to know all objects' states (position and velocity), their intentions (to maneuver), and the uncertainty associated with that information. We also need to know the size and mass of each object to assess the consequences, since miss distance or even probability of collision alone is not sufficient.

Nine years since the Iridium-Cosmos collision, what do we have? Only the US government currently provides space situational awareness (SSA) data to the public. But they don't provide data on all satellites. They don't provide data on where their military or intelligence satellites are—or even for some allies—even though other countries and even amateurs can see them. They also don't provide data on objects that they don't know where they came from (analyst sats). As a satellite operator, not knowing there is a satellite near you will not prevent a collision.

They don't provide the same data to all operators. Some get TLEs (not really suitable) and some get SP ephemeris. These paint conflicting pictures of what's going on. TLEs have no uncertainty information. SP data does, but only the data provided in a Conjunction Data Message (CDM) contains covariance (usually). But you only get a CDM when JSpOC thinks there is a close approach. If they aren't screening with operator ephemerides and a satellite has recently maneuvered or will soon, operators may miss actual close approaches or be notified on non-existent ones. There is rough size data but no mass data.

The result is a mix of inconsistent and conflicting portrayals of the environment that jeopardizes not only safety of flight for individual satellites, but potentially the overall near-Earth space environment. How could this be? Doesn't the US government want to keep its satellites safe and preserve the space environment?

The problem comes down to transparency. Having a military organization responsible for collecting all observations and performing conjunction analysis in a black box does not produce transparency (or trust). In reality, it is unrealistic to expect any military organization to be transparent since there can often be valid reasons to withhold information that might jeopardize national security, such as capabilities or limitations of sensor systems.

So, we've reached a point in our journey where we realize we haven't yet gotten to our destination yet. But we have identified a number of obstacles to conducting a successful journey. Which road do we choose to continue our journey?

This realization is what has driven many to believe that the only possible path forward is one that is independent of any reliance on military systems—whether those are sensor networks or those processing the results—to avoid problems with transparency or changing priorities. And since this is a global problem, the solution must be international, as well.

The Space Data Association, with its broad international collaboration, has acknowledged this realization by deciding to renew their contract for the Space Data Center 2.0, which will rely on observations from a diverse network of commercial sensors combined with state-of-the-art orbit determination from AGI's ComSpOC.

While this solution doesn't represent our final destination, it seems the only viable path along our journey to move us toward that eventual destination. We hope that others will share that vision and join us on our journey.

It is time we move forward expeditiously, since failing to do so not only jeopardizes thousands of operational satellites and the missions that depend upon them, but the near-Earth space environment, as well. And we must move forward together, since even one misstep by a single operator—working with incomplete or conflicting information—puts us all at risk.

So, thank you for your time today and letting me talk story. I have to say that this has been a remarkably interesting journey so far and I look forward to continuing it with many of you here today. I hope that some of you in the audience that have experience in STM will also find an opportunity to talk story about your own journey, so that we may all develop a better appreciation of where we've been and how that might help us chart a successful path to achieving true STM. Thank you.