The National Academy of Sciences Space Studies Board (SSB)
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Space Situational Awareness, Orbital Debris Mitigation, and Hazards in the Space Commons

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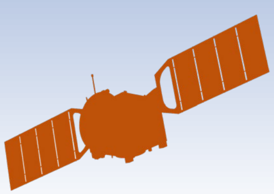
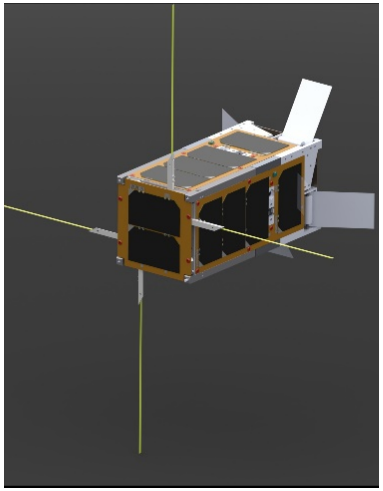
Advanced Autonomous Multiple Spacecraft

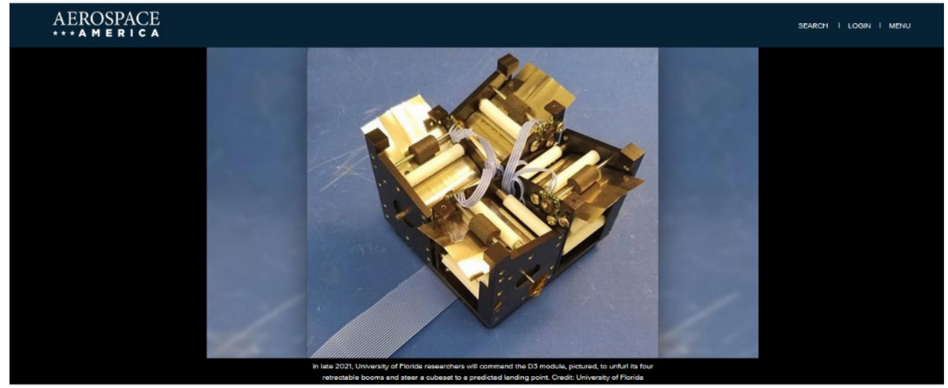


Chosen topics

1. Controlled LEO debris removal
2. Proximity identification of unknown targets
3. Fragment fly-out prediction
4. The ICSSA

D3 CubeSat : controlled re-entry from LEO and collision avoidance



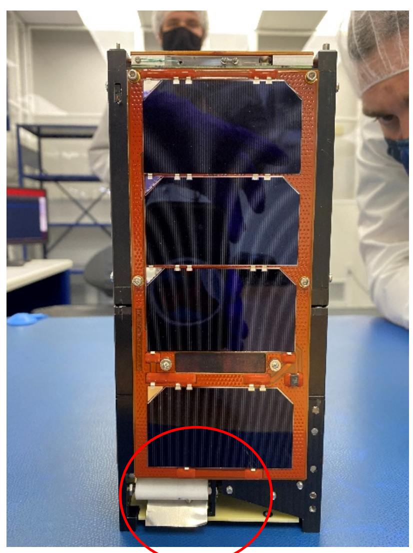


Drag Deorbit Device (D3)

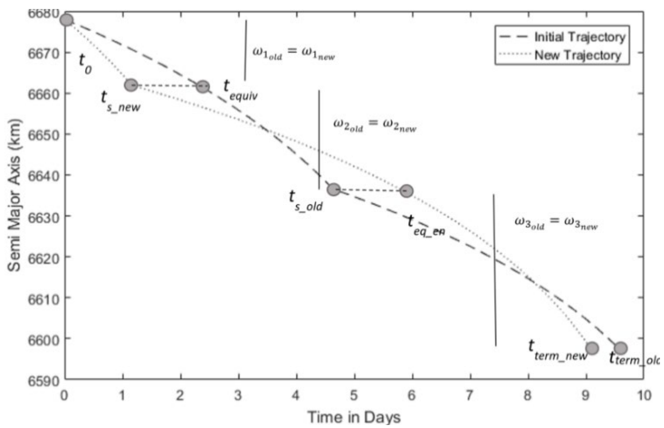
Patented & featured in Aer America

"Deorbiting plus": These University of Florida researchers want to predict where cubesats will land

BY CAT HOFACKER | JANUARY 7, 2021



D3: controlled re-entry from LEO



According to section 4.7.2.1 of the NASA debris mitigation guidelines[1], a selected trajectory for guided re-entry must ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.

[1]"Process for Limiting Orbital Debris," NASA-STD-8719.14A, May 2012.

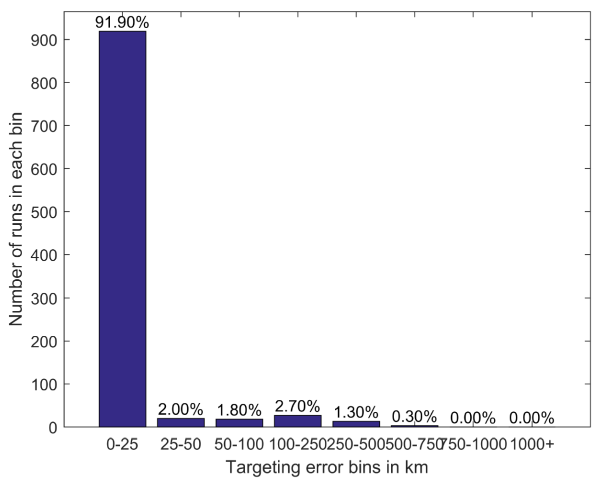


Figure 13: Guidance Errors from Monte Carlo Simulations

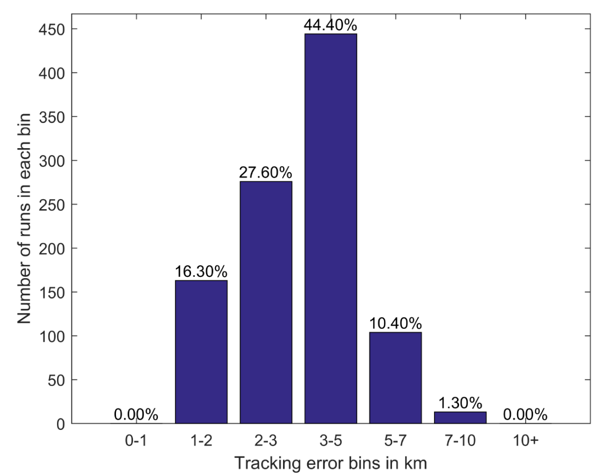
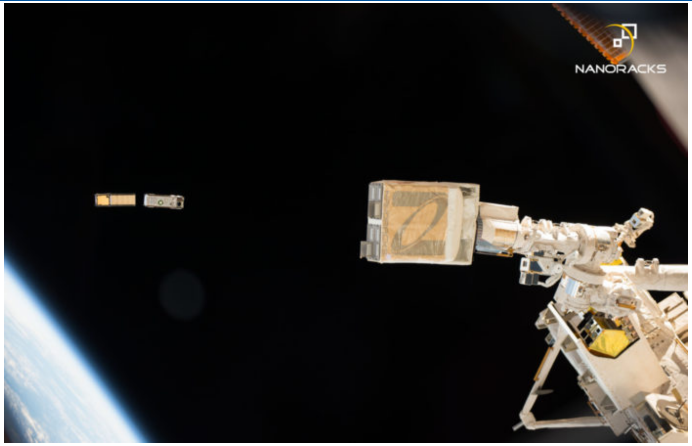


Figure 14: Maximum Guidance Tracking Errors from Monte Carlo Simulations

Deployment from ISS via NanoRacks in July (tentative) and references



Alberto Fedele, Sanny Omar, Stefania Cantoni, Raffaele Savino, Riccardo Bevilacqua, “Precise re-entry and landing of propellantless spacecraft”, Advances in Space Research, Volume 68, Issue 11, 1 December 2021, Pages 4336-4358.

Sanny Omar, Camilo Riano-Rios, Riccardo Bevilacqua, "The Drag Maneuvering Device for the Semi-Passive Three-Axis Attitude Stabilization of Low Earth Orbit Nanosatellites', the Journal of Small Satellites (JoSS), Vol. 10, No. 01 (Feb. 2021), pp. 943–957.

S. Omar and R. Bevilacqua, " **Spacecraft Collision Avoidance using Aerodynamic Drag**" JOURNAL OF GUIDANCE,CONTROL,AND DYNAMICS, Vol. 43, No. 3, March 2020, https://arc.aiaa.org/doi/pdf/10.2514/1.G004518.

Sanny Omar and Riccardo Bevilacqua, "Hardware and GNC Solutions for Controlled Spacecraft Re-Entry using Aerodynamic Drag", Volume 159, June 2019, Pages 49-64, Acta Astronautica.

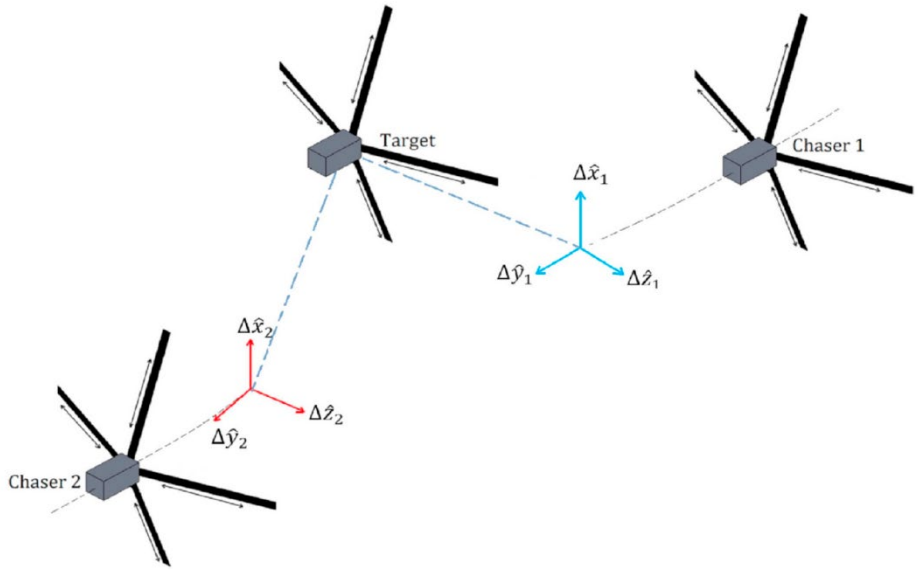
S. Rafano, S. Omar, D. Guglielmo, R. Bevilacqua, “SAFETY ANALYSIS FOR SHALLOW CONTROLLED RE-ENTRIES THROUGH REDUCED ORDER MODELING AND INPUTS’ STATISTICS METHOD”, Volume 155, February 2019, Pages 426-447, Acta Astronautica.

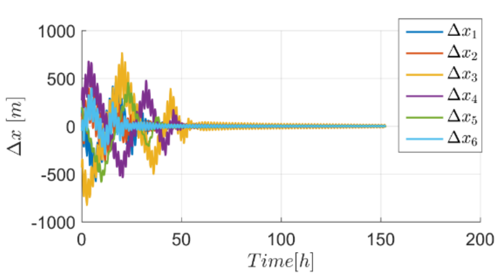
S. Omar, R. Bevilacqua, “GUIDANCE, NAVIGATION, AND CONTROL SOLUTIONS FOR SPACECRAFT RE-ENTRY POINT TARGETING USING AERODYNAMIC DRAG”, Volume 155, February 2019, Pages 389-405, Acta Astronautica.

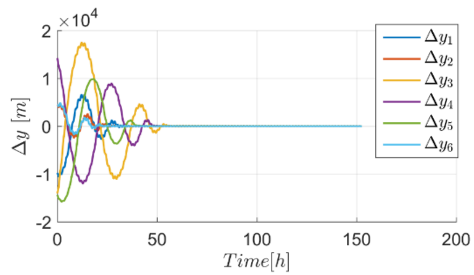
D. Guglielmo, S. Omar, R. Bevilacqua, et al., "Drag De-Orbit Device - A New Standard Re-Entry Actuator for CubeSats", Journal of Spacecraft and Rockets, Vol. 56, No. 1 (2019), pp. 129-145.

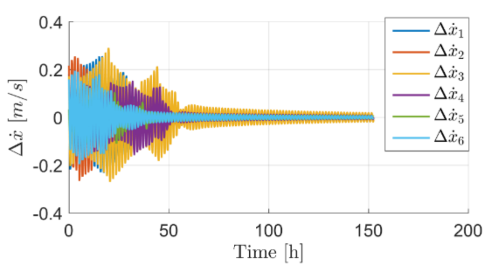
Sanny Omar, Riccardo Bevilacqua, et al., “Spacecraft De-Orbit Point Targeting using Aerodynamic Drag”, Vol. 40, No. 10 (2017), pp. 2646-2652, Journal of Guidance, Control, and Dynamics.

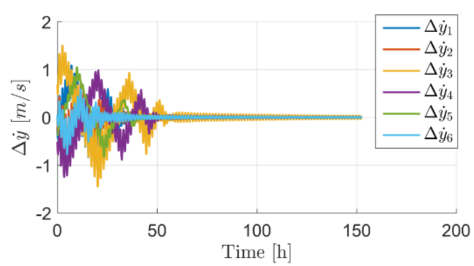
Localized SSA focusing on system ID of deorbiting S/C (target unknown)

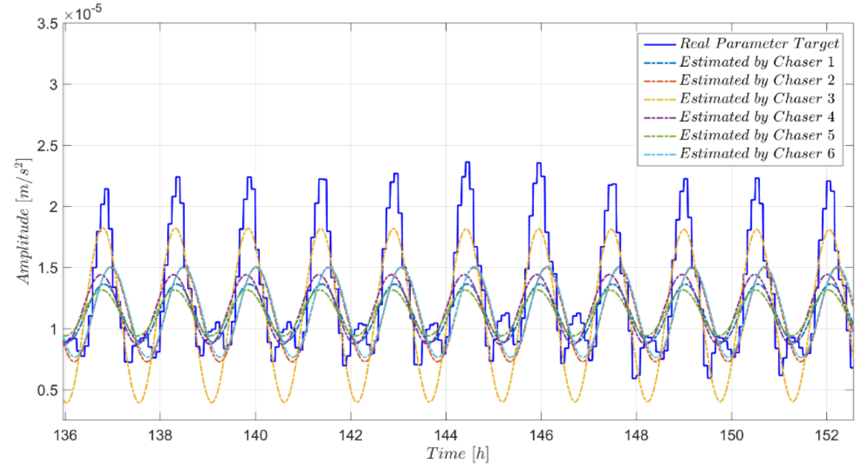












References

Camilo Riano-Rios, Runhan Sun, Riccardo Bevilacqua, Warren Dixon, "Aerodynamic and Gravity Gradient based Attitude Control for CubeSats in the presence of Environmental and Spacecraft Uncertainties", Acta Astronautica, Volume 180, March 2021, Pages 439-450, https://doi.org/10.1016/j.actaastro.2020.12.038.

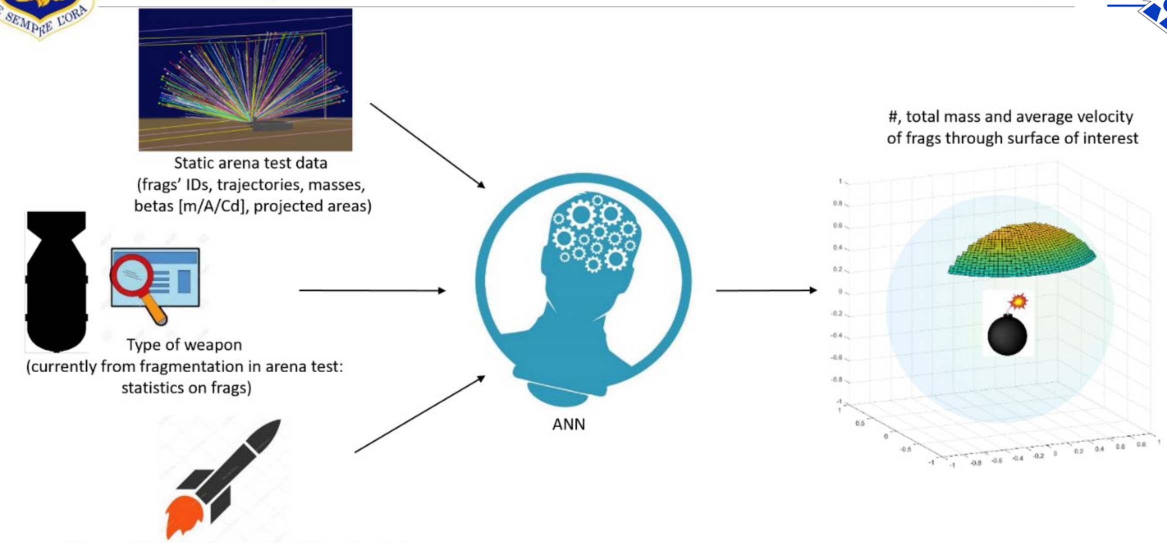
Runhan Sun, Camilo Riano-Rios, Riccardo Bevilacqua, Norman Fitz-Coy, Warren Dixon, "CubeSat Adaptive Attitude Control with Uncertain Drag Coefficient and Atmospheric Density", JOURNAL OF GUIDANCE,CONTROL,AND DYNAMICS, published online Dec. 2020: https://doi.org/10.2514/1.G005515

Camilo Riano-Rios, Riccardo Bevilacqua, Warren E. Dixon. 2020 Differential Drag-Based Multiple Spacecraft Maneuvering and On-Line Parameter Estimation Using Integral Concurrent Learning. Volume 174, September 2020, Pages 189-203, Acta Astronautica, https://www.sciencedirect.com/science/article/pii/S0094576520302745

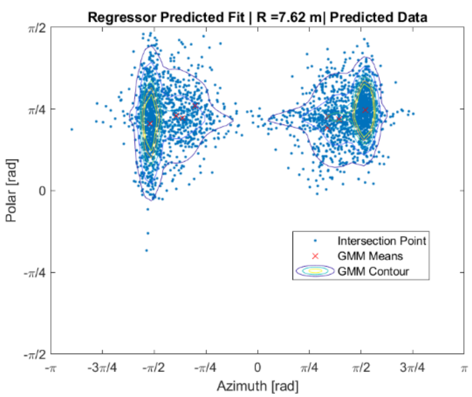
Camilo Riano-Rios, Riccardo Bevilacqua, Warren E. Dixon, "Adaptive Control for Differential Drag-Based Rendezvous Maneuvers with an Unknown Target", Invited for an Acta Astronautica Special Issue associated with the 2nd International Academy of Astronautics Conference on Space Situational Awareness. https://www.sciencedirect.com/science/article/pii/S0094576520301399

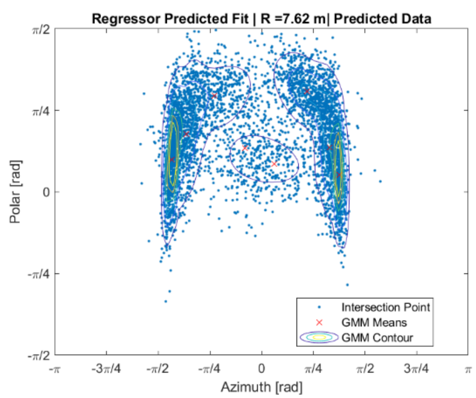
Warhead fragment fly-out predictions using AI (potential extension to space debris modeling)

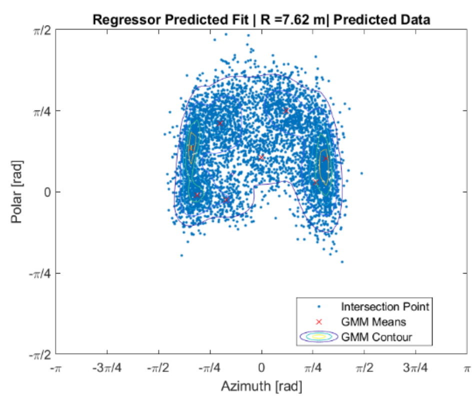
The main question: can we create a transfer function from static arena tests to in-flight conditions?



Omkar Mulekar, Riccardo Bevilacqua, Elisabetta Jerome, Thomas Hatch, "Transfer Function to Predict Warhead Fragmentation In-Flight Behavior from Static Data", AIAA Journal, https://doi.org/10.2514/1.J060226.







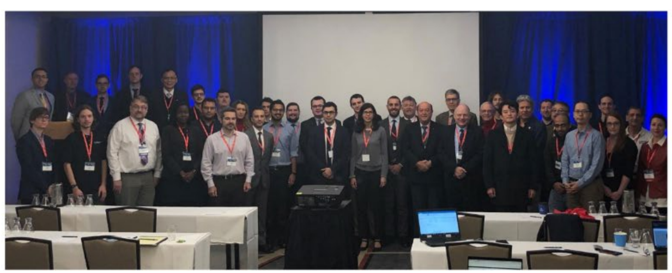
Space collisions and explosions connections? Not really…the "Examples of Technology Transfer from the SDIO Kinetic Energy Weapon Lethality Program to Orbital Debris Modeling" **does not show a single equation. It is all descriptive, not quantitative.**

International Academy of Astronautics Conference on Space Situational Awareness

1st IAA Conference on Space Situational Awareness (ICSSA) Orlando, FL, USA, Nov. 13-15, 2017

The ozone hole is in recovery thanks to the Montreal agreement. Unlike the ozone problem, Earth orbits congestion and collisions in space will not solve themselves by simply stopping orbital injections. “We need to fix this plane while it is flying”. And we have to do it yesterday.

2nd IAA Conference on Space Situational Awareness (ICSSA) Washington DC, USA, Jan 14-16, 2020



The ozone hole is in recovery thanks to the Montreal agreement. Unlike the ozone problem, Earth orbits congestion and collisions in space will not solve themselves by simply stopping orbital injections. “We need to fix this plane while it is flying”. And we have to do it yesterday.

ICSSA Stats

2017:
1. 91 attendees
2. 16 countries (including Brazil, Canada, China, European Union (ESA), France, Italy, Germany, Spain, Hong Kong, Korea, Poland, Russia, Switzerland, Ukraine, United Kingdom, and the United States).
3. 15 US States (Alabama, Arizona, California, Colorado, Florida, Georgia, Maryland, Missouri, North Carolina, New Mexico, Ohio, South Carolina, Texas, Virginia, and Washington State).
4. U.S. Government Involvement from AFOSR/EOARD, NASA, Lockheed Martin Corporation, and the U.S. Air Force.
5. 4 keynote speakers.

2020:
1. 62 attendees
2. 10 countries (including Egypt, France, Italy, India, Republic of Korea, Poland, Spain, Switzerland, United Kingdom, and United States).
3. 12 US States (Alabama, Colorado, Washington DC, Florida, Georgia, Hawaii, Massachusetts, Maryland, New York, Pennsylvania, Texas, and Virginia).
4. 3 keynote speakers.
5. 1 Workshop on Engineering to Speak
6. Special Presentation on Implementing SPD-3: The Dynamic Roles of Industry & Interagency from Dr. Diane Howard, U.S. Department of Commerce

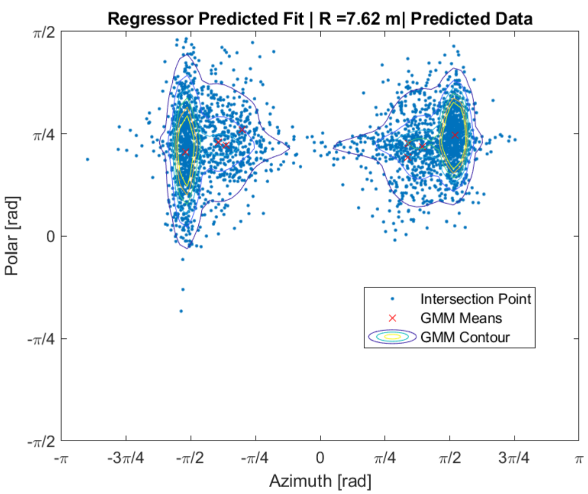
ICSSA Stats

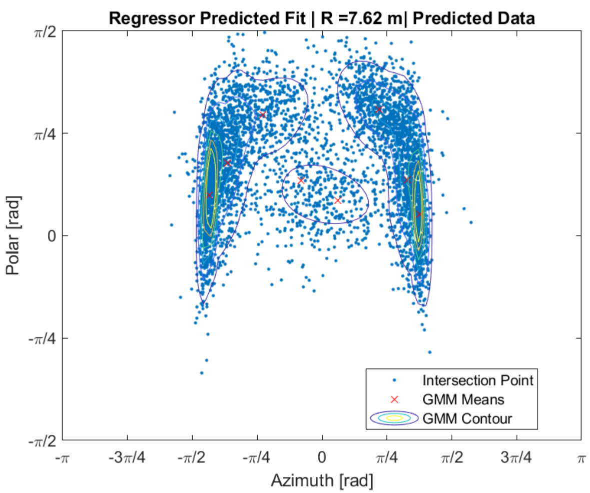
2022:

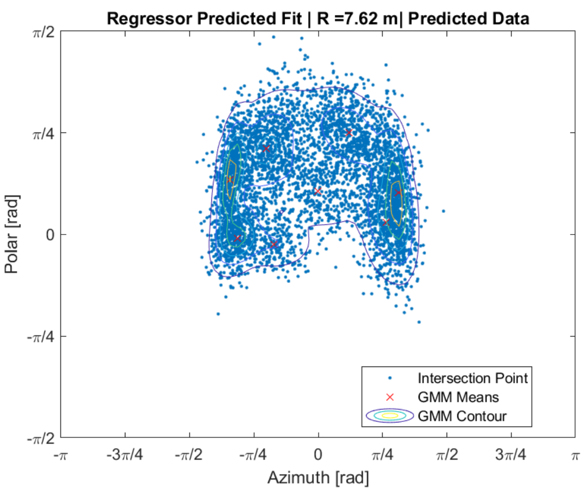
1. 77 Attendees
2. 18 Countries (Australia, Brazil, Canada, China, France, Germany, India, Italy, Japan, Netherlands, Nigeria, Romania, Slovak Republic, Spain, Switzerland, Turkey, United Kingdom, United States)
3. 9 US States (Colorado, Florida, Indiana, New York, Ohio, Pennsylvania, Texas, Utah, Virginia
4. 5 Keynote Speakers
5. 58 Papers

Fragment fly-out predictions: results so far

- Given detonation state and radius, predict GMM and Total Number of Fragments N_{total}
    - Randomly generate from GMM distribution N_{total} intersection points
- Case: Pitch, Yaw, Roll 0 deg
    - Speeds 0 m/s, 305 m/s, 610 m/s
    - Radius 7.6 m

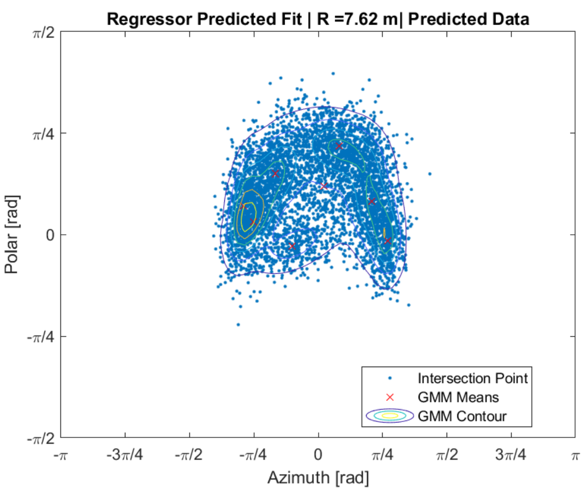


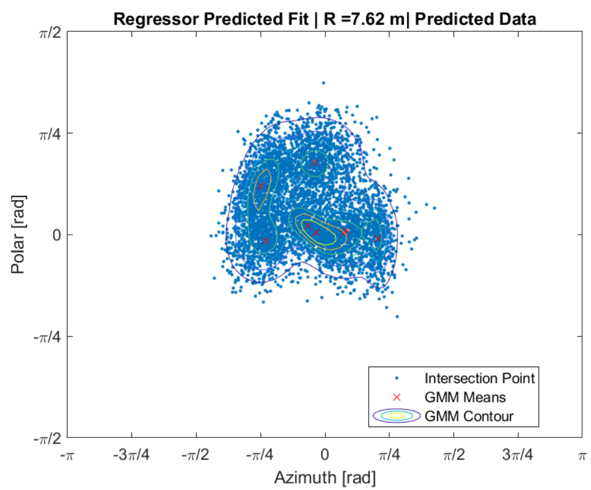


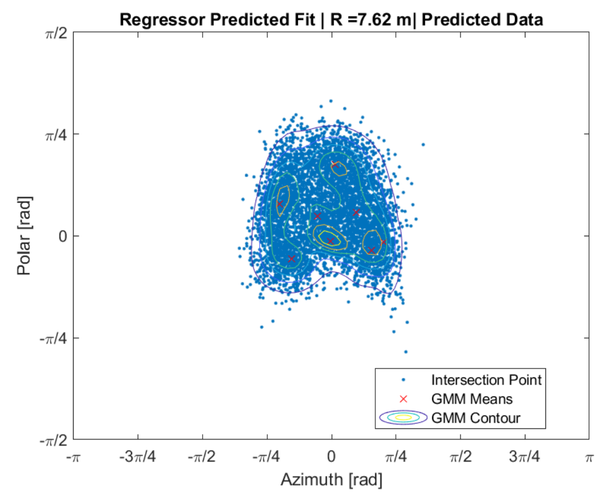


Increasing velocity

- Case: Pitch, Yaw, Roll 0 deg
  - Speeds 915 m/s, 1220 m/s, 1525 m/s
  - Radius 7.6 m







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