# SALVATORE ALFANO

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## EDUCATION

Air War College (Correspondence), 1995

Space Operations Orientation Course, 1994

Ph.D. in Electrical and Computer Engineering, University of Colorado, 1988

Air Command and Staff College (Correspondence), 1984

Master of Science in Astronautical Engineering, Air Force Institute of Technology, 1982 – Distinguished Graduate

Squadron Officer's School (Residence), 1978

Pilot Instructor Training, Randolph AFB, TX, 1976

Undergraduate Pilot Training, Moody AFB, GA, 1975 – Distinguished Graduate

Bachelor of Science in Astronautical Engineering, US Air Force Academy, 1974

## EXPERIENCE

2020-Present: **Senior Research Astrodynamicist for Commercial Space Operations Center, Inc.**

Develops new methods to enhance/improve space operation support. Promotes optimum use of space assets to further enhance U.S. security and public awareness of space information. Fosters innovation in space control, technology, commerce, and exploration. Acts as a central resource for open, readily available, industry-wide standards to encourage interoperability. Compiles and disseminates accurate industry information, including the most capable techniques, sources, practices, and tools for space and defense applications.

Works in a team environment applying various computer science and system development techniques to solve a wide variety of problems related to spacecraft conjunction risk analysis and mitigation. Executes on all system development lifecycle aspects that meet customer requirements and often exceed their expectations. Performs software maintenance and enhancement to the conjunction assessment systems. Perform system requirements analysis, alternative design analysis, software development, system test planning & execution, & deployment & integration activities.

2004-2020: **Senior Research Astrodynamicist for Analytical Graphics, Inc.**

Develops new methods to enhance/improve space operation support. Promotes optimum use of space assets to further enhance U.S. security and public awareness of space information. Fosters innovation in space control, technology, commerce, and exploration. Acts as a central resource for open, readily available, industry-wide standards to encourage interoperability. Compiles and disseminates accurate industry information, including the most capable techniques, sources, practices, and tools for space and defense applications.

Works in a team environment applying various computer science and system development techniques to solve a wide variety of problems related to spacecraft conjunction risk analysis and mitigation. Executes on all system development lifecycle aspects that meet customer requirements and often exceed their expectations. Performs software maintenance and enhancement to the conjunction assessment systems. Perform system requirements analysis, alternative design analysis, software development, system test planning & execution, & deployment & integration activities.

2000-2003: **Senior Project Engineer for the Aerospace Corporation**

Develops new methods to enhance/improve space operation support relating to orbit determination, collision avoidance, radio frequency interference, and incidental laser illumination. Provides collision avoidance support as needed for commercial and government customers.

Educates Space Command leadership concerning astrodynamics and operational issues.

1996- 1999: **Vice-Director of Analysis for USSPACECOM and NORAD**

Second in Command of Directorate. Assigns, prioritizes, and manages directorate activities. Develops and/or acquires models and simulations to support Commands' analysis. Assesses mission systems and performance. Oversees task implementation and execution within the Modern Aids to Planning Program sponsored by JS/J-8 and other Defense-wide initiatives.

1992-1996: **Chief, Space and Missiles Dynamics Division, Phillips Lab, NM**

Plans, integrates, executes, and directs R&D of astrodynamics projects. Supervises elite team of 10 military and civilian scientists in developing methods for orbital simulation and testing of computer models. Engineers key subsystems for unique surveillance technologies in support of highly classified national assets.

1988-1992: **Associate Professor of Astronautics, US Air Force Academy**

Research Director--directed 12 officers working research projects for SDI, AF Space Command, and AF Systems Command.

Astro Division Chief--Supervised largest curriculum change in a decade, successfully achieved national accreditation.

Deputy for Labs and Research--Managed three labs ($100M+), oversaw research efforts, directed annual budget for Astro Department.

TG-7A Instructor Pilot

1985-1988: **Graduate Student, University of Colorado at Colorado Springs.**

1983-1985: Instructor and Assistant Professor of Astronautics, US Air Force Academy

Course directed courses in Astrodynamics, Controls, and Space Systems.

Rebuilt linear systems course and developed computer aided instruction tools.

Designed, built, and tested STS and MMU Simulators

T-41 Instructor Pilot

1981-1982: **Graduate Student, Air Force Institute of Technology, WPAFB.**

Alfano, S., Center for Space Standards and Innovation
27 May 2021
**RESEARCH COMPLETED:**

**2020: Risk assessment of recent high-interest conjunctions (with Dan Oltrogge and others)**

Examined the timeline, activities, and risks associated with two, recent, high-profile space events: the conjunctions of the Aeolus and Starlink spacecraft (both maneuverable) and the IRAS and GGSE-4 spacecraft (both dead). Fused observations from the Space Surveillance Network (SSN) to produce a sequence of high-accuracy orbit solutions and used that sequence to generate three-dimensional, dynamic progressions of each conjunction's miss distance, collision probability and its relation to the dilution threshold. Employed the Probability of Collision (Pc) tool to assess the conjunction threat evolution. Estimated the potential debris fields that these events may have generated had they occurred and then assessed the impact of these fragmentation fields upon estimated operator workload and subsequent collision risk.

**2020: Leo Constellation Encounter and Collision Rate Estimation Update (with Dan Oltrogge)**

Updated our previous encounter and collision rate estimates for the current resident space object catalog. New for this update, estimated collision rates also incorporate planned and/or hypothetical (New Space) large constellations based on a multitude of license filings and applications. Collision estimates refined based on estimated object sizes to better represent collision risk with the satellite population. The current public space catalog was additionally augmented by a MASTER model-based representative catalogue of small debris too small to currently track, but which may soon be tracked and maintained by new SSA sensors and systems. Also consider were elements of information which may be relevant to assembling a useful metric for evaluating a constellation's collision fragmentation potential. As a demonstration, a kinetic energy is adopted and applied to the entire set of proposed large constellations having a current license application to facilitate a comparative assessment and rank ordering of the impact of each proposed large constellation. These results indicate that collision risk in LEO is fairly high when examined in the context of a satellite constellation's lifetime.

**2019: The Cost of Not Doing Debris Remediation (with Dan Oltrogge)**

Rather than trying to estimate the cost of Active Debris Removal (ADR) operations, we examined the costs of not urgently implementing debris remediation countermeasures such as ADR or just-in-time collision avoidance (JCA). The current analysis of the most likely massive-on-massive collisions in low Earth orbit (LEO), as characterized by the ongoing Massive Collision Monitoring Activity (MCMA), is used to identify two plausible scenarios for debris-generating events and their collision risk to the population of operational satellites. The interaction of the likely massive collision events and the current operational payload population is examined to estimate the cost to the global community if inaction in debris remediation activities continues. The "cost" of these events will include (1) direct loss of satellite capability from lethal nontrackable (LNT) debris collision risk and (2) collision avoidance (CA) burden on operational satellites.

**2019: Variance-Covariance Significant Figure Reduction and Its Effect on Collision Probability Calculation**

I examine the effects of elemental reduction in the number of covariance matrices significant figures. Sometimes this reduction can cause an otherwise positive definite covariance matrix to appear semi-definite or indefinite. I examine over one million covariance matrices from CDMs and a previous publication by reducing the number of significant digits while retesting for positive definiteness and suitability for estimating collision probability metrics. Four individual reduction techniques are studied: rounding all elements, rounding up all elements, truncating all elements, and rounding up all diagonal elements while truncating all off-diagonal elements. Results indicate that, for most cases, at least six significant figures are required.

**2018: Low-Thrust Transfer Nomograms**

A nomogram (or nomograph) is a graphical representation of three or more pieces of data; knowledge of two of those values visually leads to the other(s). Typically, a sharp pencil and keen eye will produce results within 5% of an exact numerical solution. I construct some useful nomograms regarding minimum-time, continuous low-thrust, circle-to-circle, orbit transfers in addition to nomograms relating miss distance to off-cycle thrust time as well as to maximum probability. The nomograms are useful for pre-mission planning and determining if further numerical processing is even worth the bother. Their main advantages are that no software or licenses are required, nor even understanding of the underlying fundamentals. All that is needed is a straight edge, a sharp pencil, and good eyesight. In a matter of seconds one can arrive at proximate answers, making them very convenient for initial assessments. Conference Paper presented at **AAS/AIAA Astrodynamics Specialist Conference**.

**2017: Characterization of Satellite Conjunction Walk-ins (with Dan Oltrogge)**

We examined satellite conjunction walk-ins consisting of a time-ordered sequence of five or more close approaches within 10 km between a pair of orbiting objects, with each conjunction spaced at approximately full-orbital period apart from the former and subsequent ones. For geosynchronous orbits the sequence can be within 50 km. A volumetric approach is employed to determine the possibility of a walk-in while also determining the true anomalies of chief and deputy that yield the closest possible approach. Using an orbit element difference vector, we identify the conditions which lead to such conjunction walk-in sequences. We employ a linearized approach to examine the various close approach patterns that result from these and other approach geometry conditions. In doing so we formulate a hybrid approach to determining the Clohessy-Wiltshire-Hill coefficients that is more accurate than the original formulation. We depict all three dimensions to simultaneously examine the evolution of miss-distance over time for a specific walk-in. Realizing that linearized relative motion techniques are not adequate for all cases; our purpose is to use linearization as a window to gain understanding of the underlying mechanics of conjunction walk-ins. Published in **Acta Astronautica.**

**2017: Comprehensive assessment of collision likelihood in Geosynchronous Earth Orbit (with Dan Oltrogge and others)**

Knowing the likelihood of collision for satellites operating in Geosynchronous Earth Orbit (GEO) is of extreme importance and interest to the global community and the operators of GEO spacecraft. We employed six independent and diverse assessment methods to estimate GEO collision likelihood. Taken in aggregate, this comprehensive assessment offers new insights into GEO collision likelihood that are within a factor of 3.5 of each other. These results are then compared to four collision and seven encounter rate estimates previously published. Collectively, these new findings indicate that collision likelihood in GEO is as much as four orders of magnitude higher than previously published by other researchers. Results indicate that a collision is likely to occur every 4 years for one satellite out of the entire GEO active satellite population against a 1 cm RSO catalogue, and every 50 years against a 20 cm RSO catalogue. Further, previous assertions that collision relative velocities are low (i.e., < 1 km/s) in GEO are disproven, with some GEO relative velocities as high as 4 km/s identified. Published in **Acta Astronautica.**

**2016: Collision Risk in Low Earth Orbit (with Dan Oltrogge)**

Knowing the collision risk of satellites operating in Low Earth Orbit (LEO) is of great importance and interest to the global space community and operators of LEO spacecraft. New methods for developing a representative catalogue and for determining typical encounter rates for small spacecraft sizes offer ways to address the technical complexities of assessing collision risk. We employ these new methods to estimate LEO collision risk for both current, planned and hypothetical constellations. These results indicate that collision risk in LEO is fairly high when examined in the context of a satellite constellation's lifetime. Presented at **67th International Astronautical Congress (IAC).**

**2016: Probability of Collision: Valuation, Variability, Visualization, and Validity**

**(with Dan Oltrogge)**

An overview of the types of Pc estimation techniques is provided. For each technique, the inputs it requires are delineated. Three-dimensional, interactive tools are then presented for depicting the variability of the Pc inputs to Pc estimates. These depictions are then used to quantify the quality of Pc input data required to yield actionable Pc estimates.

**2015: Enhanced fast lifetime probability algorithm (with Dan Oltrogge)**

Augmented spheres (from 2014 work) with ellipsoids.

**2015: Updated Covariance Transformations for Satellite Flight Dynamics Operations (with Dave Vallado)**

As covariance estimates are becoming more widely available as flight dynamics operations work towards greater accuracy we examined how covariance matrices are propagated, to include orbital state formats and coordinate systems. Various equations to convert between orbital state formats and satellite coordinate systems are essential to correctly comparing each approach. The literature contains many partial examples. Vallado (2003) presented a complete set of equations, but advised that a few inconsistencies were found. We have corrected those errors and provide the results. Test results are given for several cases, and we have made our MATLAB code available.

**2014: Developed fast lifetime probability algorithm (with Dan Oltrogge)**

Minimization of post-mission long-term collision risk cannot be based on positional error uncertainty volumes or in-track positions, since those inputs cannot be anticipated. We developed an approach for multi-year encounter screening of any pair of satellites, which by extension can evaluate an individual satellite against an entire space object catalog or even "all-on-all" collision risk. We define a path-centered ring torus about a second satellite's orbit and assessing if/when the first satellite's orbit penetrates this torus. The position of each object is assumed to be uniformly distributed in mean anomaly along its orbit in order to determine the probability of both objects being within a specified distance. J2 effects, solar radiation pressure and luni-solar perturbations are considered. This approach is suitable for all circular, elliptical and relatively-inclined orbits. This method can be used to identify graveyard orbits that are least likely to produce encounters over many years.

**2013: Performed satellite conjunction filter characterization study (with David Finkleman)**

Extended concepts of signal detection theory to predicting the performance of conjunction screening techniques and guiding the selection of keep-out and screening thresholds. Every filtering process is vulnerable to including objects that are not threats and excluding some that are threats, Type I and Type II errors. The approach in this research guides selection of the best operating point for any filters suited to a user's tolerance for false alarms and unwarned threats by providing a sound and traceable formalism for selecting filter parameters.

**2012: Developed curvilinear coordinate transformation for relative orbital motion (with David Vallado)**

Developed and characterized the accuracy of the transformation between Cartesian and a modified Equidistant Cylindrical (EQCM) space for both position and velocity vectors. This included exercising the transformation in both directions. Quantified and qualified the ability of the transformation to work on various orbital types (LEO, MEO, HEO, GEO, etc.). Documented the improvement in accuracy from traditional Hill's solutions for each case – quantified the error introduced by Hill's solutions for larger satellite separations.

**2011: Developed probability-based distance threshold for conjunction screening.**

Developed an analytical approximation that relates maximum probability to a miss distance threshold, thereby ensuring that the screening distance is adequate for probability-based conjunction assessment. To reduce processing time, satellite conjunction prediction tools often employ methods to decrease the number of objects for consideration. Various economizing filters are used to identify orbiting pairs that cannot come close enough over a prescribed time period to be considered hazardous. Such pairings can then be eliminated from further computation to quicken the overall processing time. For each pair that remains, the respective orbits are propagated to determine if the minimum distance between objects is below a preset screening threshold. When conjunction probability is to be used as metric, the minimum distance threshold must be determined from the minimum acceptable probability threshold.

**2010: Developed toroidal path conjunction screening filter.**

Rather than using a single distance bound, this work presents a toroid approach, providing a measure of versatility by allowing the user to specify different in-plane and out-of-plane bounds for the path filter. For satellite conjunction prediction containing many objects, timely processing can be a concern. Various filters are used to identify orbiting pairs that cannot come close enough over a prescribed time period to be considered hazardous. Such pairings can then be eliminated from further computation to quicken the overall processing time. One such filter is the orbit path filter (also known as the geometric pre-filter), designed to eliminate pairs of objects based on characteristics of orbital motion. The goal of this filter is to eliminate pairings where the distance (geometry) between their orbits remains above some user-defined threshold, irrespective of the actual locations of the satellites along their paths. The primary orbit is used to define a focus-centered elliptical ring torus with user-defined thresholds. An assessment is then made to determine if the secondary orbit can touch or penetrate this torus. The method detailed here can be used on coplanar, as well as non-coplanar, orbits.

Published in **Celestial Mechanics and Dynamical Astronomy**.

**2009: Developed method to assess the vulnerability of a satellite to a missile or co-orbiting platform.**

Vulnerability is represented as an engagement volume for a specific missile relative to its launch platform. Alternately, the vulnerability is represented as a geographical footprint relative to satellite position that encompasses all possible launcher locations for a specific missile. Three engagement solutions are found that account for spherical earth rotation. One solution finds the maximum missile range for an ascent-only trajectory while another solution accommodates a descending trajectory. In addition, the ascent engagement for the descending trajectory is used to depict a rapid engagement scenario. These preliminary solutions are formulated to address ground-, sea-, or air-launched missiles. For space-based threats orbital dynamics are used to initially assess the vulnerability of a satellite to a Space-Based Interceptor (SBI) launched from an orbiting, anti-satellite, carrier platform. The method produces an engagement volume derived from the position and velocity vectors of the launching platform, the range of impulsive velocities that can be imparted to the SBI upon deployment, and the maximum expected time-of-flight from release until intercept. The results are shown as points in space contained within a convex hull or a minimum volume enclosing ellipsoid and are displayed relative to the orbiting carrier platform.

Conference Paper presented at **AAS/AIAA Astrodynamics Specialist Conference**.

**2008: Developed Monte Carlo process to assess the satellite collision probability computations.**

Monte Carlo process assesses the satellite collision probability computations of various methods and obtains a preliminary estimate on their bounds of utility. No assumptions are made regarding the constancy or direction of the relative velocity over the encounter's time span. Two statistical bounding criteria are used to determine the minimum number of cases needed. This particular work is meant to assure the consistency of the Gaussian process from epoch to closest approach point for the chosen force model.

Conference Paper presented at **AAS/AIAA Space Flight Mechanics Meeting**.

**2007: Developed method to accommodate any object shape in probability computations for both linear and nonlinear relative motion.**

Refines probability calculations to accommodate any object shape, even if it time varying. This work includes a test where a fractional probability threshold is set based on a given accuracy requirement and then used to find the minimum relative velocity that ensures sufficient linearity. Nonlinear probability is computed by breaking the collision tube into sufficiently small cylinders such that the sectional motion is nearly linear, computing the linear probability associated with each section, and then summing. Two approaches are taken to determine the nonlinear probability. The first considers each cylinder end to be perpendicular to its axis and does not account for gaps or overlaps of the abutting cylinders. The second is more complex, using bundled, rectangular parallelepipeds to eliminate these gaps and overlaps by treating the junctions as compound miters while simultaneously incorporating probability density variations.

Conference Paper presented at **AAS/AIAA Astrodynamics Specialist Conference**.

**2005: Developed Collision Avoidance Maneuver Planning Tool.**

Developed MATLAB analysis tool that can perform parametric studies of single-axis and dual-axes maneuvers. The user inputs the object pair's positions, velocities, covariances, and physical sizes. The tool allows the user to modify the covariances and physical object sizes on the fly. MATLAB then creates collision-probability contour plots for a range of user-specified maneuver times and velocity changes. To reduce risk to an acceptable level, the user selects from a family of possible maneuvers. The candidate maneuver is can then be further analyzed to address other maneuver concerns. Conference Paper presented at **AAS/AIAA Astrodynamics Specialist Conference**.

**2004: Developed method to accommodate non-spherical shapes in probability computations.**

Refines probability calculations for rectangular object shapes of unknown orientation and compares those results to their representations as spheres. For rectangular objects in the absence of object attitude information, a footprint is created that completely defines the region where the two objects might touch. This footprint is then rotated to determine the orientation that produces the largest probability making it the most conservative estimate for the given conjunction conditions. Conference Paper presented at **AAS/AIAA Astrodynamics Specialist Conference**.

**2004: Developed method to interpolate orbital covariance.**

Derives two interpolators to determine the intermediate covariance of a space object's position. Two considerations are given to the derivations. The first is that the covariance matrix changes direction and shape with orbital motion as reflected in its first and second derivatives with respect to time. In the absence of such derivatives, the second consideration is that covariance growth can be reasonably modeled by including data that is outside the immediate time interval of concern. These two considerations incorporate orbital motion with time-associated covariance growth/reorientation to produce realistic intermediate covariance matrices while precisely matching them at the start and end of a given time interval. Conference Paper presented at **AAS/AIAA Spaceflight Mechanics Meeting**.

**2003: Developed method to determine probability dilution regions.**

Shows the effects of positional uncertainty on the Gaussian probability computation for orbit conjunction. Regions of maximum probability are mapped for various satellite sizes, encounter geometries, and covariance sizes and shapes. Those regions are then examined to assess probability dilution. Dilution occurs when the probability, although mathematically correct, is associated with poor data, not low risk. The assertion is made that orbit positional estimates should be sufficiently accurate to avoid these dilution regions. Charts and equations are created to assist an operator in determining orbital accuracy requirements that will prevent or minimize dilution of the probability calculations. If better data is not available, then the maximum probability should be used. Conference Paper presented at **AAS/AIAA Spaceflight Mechanics Meeting.**

**2001: Developed probability-based method to determine risk of laser impingement.**

Predictive avoidance analysis for laser emissions should reasonably ensure that neighboring objects are not inadvertently illuminated. Such analysis should assess the risk of satellite-to-satellite and satellite-to-ground communication interference. For high-energy lasers, it is imperative to balance mission objectives against possible degradation or disruption of neighboring objects. This work represents the uncertainties associated with emitter location and object position by three-dimensional Gaussian probability densities, then calculates the probability of direct laser impingement on a secondary object. A new analytical method is introduced to reduce computational burden. Published in the **AIAA Journal of Spacecraft and Rockets**

**2000: Developed analytical method to determine if two ellipsoids share the same volume.**

As the US Satellite Catalog transitions from General Perturbations to Special Perturbations, the accuracy (covariance) of each object will be readily available. These covariances can be used to determine probability of collision, radio frequency interference, and/or incidental laser illumination. Because the probability calculations can be computationally burdensome, it is desirable to prescreen candidate objects based on user-defined thresholds. Specifically, each object can be represented by a covariance-based ellipsoid and then processed to determine if they share some space in common. Ellipsoids (or their projections) that do not touch or overlap can be eliminated from further processing. To date, all prescreening methods involve numerical searches. The method developed is the first analytical method of its kind. Published in the **AIAA Journal of Guidance, Control, and Dynamics.**

**1995-1996: Developed advanced laser clearing house method.**

Accidental laser illumination of a neighboring satellite is an international concern. Based on the laser's power and the satellite's proximity to the line-of-sight, damage can be done to sensors and such. I developed and then refined filters to screen satellites from a candidate list. The remaining satellite orbits are examined to determine conical entry and exit times of spacecraft, if any. The method is very fast (near real-time on a personal computer) and need not be tied to a single type of orbit propagator. My co-authors assisted with programming, validation, and technical write-up. Currently used in Analytical Graphic's Satellite Tool Kit. Published in the **AIAA Journal of Spacecraft and Rockets**

**1994-1993: Developed advanced methods to determine satellite close approaches.**

Collision avoidance is always a concern for space vehicles during insertion and once on orbit. It is necessary to predict conjunctions of spacecraft and orbiting debris to avoid loss of hardware and/or life. I developed and then refined methods to determine ellipsoidal entry and exit times of spacecraft, as well as local minima between space objects. These methods are fast and accurate; they do not require iteration, as do present methods. They are also free of any orbital restrictions, while present methods apply only to special classes of orbits. This work was favorably reviewed by US Space Command (USSPACECOM) and is currently being implemented by the Phillips Laboratory in their Debris Analysis Workstation. It is already in use by the NSA. Two papers were published in the **AAS Journal of the Astronautical Sciences**. My co-author (first journal article) assisted with verification and technical write-up. Currently used in The Aerospace Corporation's Collision Vision.

**1993: Developed continuous-thrust orbit-raising charts**.

The next generation of satellites will employ electric or nuclear thrust to transfer from one orbit to another. These forms of thrust are continuous, not impulsive, and present new challenges to mission planners. I created easy-to-use tools to assist mission planners in performing propulsion trade-off studies and determining fuel/time requirements for orbit transfers. This work defines a complicated process of global mapping to create charts that are not restricted to a specific central body; this allows interplanetary and planetary mission planning from the same charts!  These charts are universal, having no restrictions on initial thrust magnitude, intermediate eccentricity, or number of revolutions about any central body.  This work also clearly defines, for the first time, the boundaries of low, intermediate, and high thrust for the scientific community.  The user does not need to have an advanced degree or computer to use the charts; the only things needed are a straightedge, good eyesight, and a scientific calculator to perform unit conversions.  This work was favorably reviewed by The Aerospace Corporation on behalf of the Phillips Laboratory and published in the **AAS Journal of the Astronautical Sciences**.  My co-author assisted with verification and technical write-up.

**1992: Developed compact method to determine satellite average visibility periods.**

To properly task ground-based sensors, it is important to know the frequency of viewing opportunities for orbiting objects.  I developed the **Complete Method of Ratios**, a numerically efficient way to determine average visibility of a spacecraft by a ground station with multiple restrictions in range, azimuth, and elevation.  The Complete Method of Ratios quickly generates an average visibility report and is easily implemented on a personal computer.  It can be used to pre-filter a candidate satellite contact list or perform parametric studies, identifying the payoff of various upgrade strategies for a tracking station.  USSPACECOM and their contractor, KAMAN Sciences Corporation, favorably reviewed this work; the complete method was published in the **AIAA Journal of Spacecraft and Rockets**.  The initial effort dealt only with range restrictions and was published in the **AAS Journal of the Astronautical Sciences**.  My co-authors on the initial paper assisted with verification and technical write-up.

**1990-1992: Developed quick method to determine precise satellite visibility periods.**

The exact times of line-of-sight between a satellite and ground station are needed to effectively schedule communication and tracking resources; this must be done rapidly and should also provide precise viewing angles.  I defined special functions for range, elevation, and azimuth and approximated their waveforms with localized quintic polynomials; allowing the visibility times to be rapidly solved for an oblate earth.  This method is free of any orbital restrictions; previous methods applied only to special classes of orbits or required much more computer processing.  This work allows an operator to rapidly generate timetables and pointing parameters for many site/satellite pairs; these tables can then be used to optimally allocate resources throughout a given time period.  USSPACECOM and their contractor, KAMAN Sciences Corporation, favorably reviewed this effort; the complete method was published in the **AIAA Journal of Spacecraft and Rockets**.  The initial method using cubic polynomials was jointly developed with my co-authors and published in the **AAS Journal of the Astronautical Sciences**.

**1989: Developed better way to compute atmospheric parameters for launch/reentry**.

Proper modeling of launch and reentry dynamics requires good knowledge of localized atmospheric densities and pressures. Using localized cubic polynomials to fit atmospheric parameters, my co-author and I showed improved accuracy, speed, and flexibility over the current Chebyshev polynomial method. Our work was subsequently published in the **AIAA Journal of Aircraft**.

**1986-1989: Developed revolutionary fuel-saving intercept strategy for SDIO**.

The proposed Advanced Interceptor Technologies (AIT) Project defensive system (formerly Brilliant Pebbles) requires an accurate and fuel-efficient terminal guidance method. It is imperative that the intercept strategy minimizes fuel while ensuring sufficient accuracy, thereby lowering launch costs by reducing payload weight. I developed a new form of control called **Certainty Control**, along with several variations, that show significant fuel savings over present methods with current sensor technology. This new form of terminal guidance is applicable to all guided munitions, not just that in space; it reduces intermediate maneuvering in the presence of sensor noise while maintaining/improving accuracy. This control method involves a blend of deterministic and stochastic methods, something rarely done in the area of guidance and control. Although the method is sound, it required a great deal of supporting work and simulation to overcome any skepticism in the scientific community. This work was favorably reviewed by SDIO and two papers published in the **AIAA Journal of Guidance, Control, and Dynamics.** My co-author on the first paper was my dissertation advisor.

**1983-1984: Developed, built, tested, and implemented real-time proximity operation simulators for the Space Shuttle (STS) and Manned Maneuvering Unit (MMU)**.

The US Air Force Academy Department of Astronautics wanted a high fidelity relative-motion simulator to explore the realm of on-orbit operations. With the aid of cadets to physically construct the hand controllers and mockup structures of the STS aft flight deck and MMU backpack, I built and programmed the dynamics and graphics for two real-time simulators. Martin Marietta reviewed this work shortly after the maiden flight of the real MMU. To their surprise, our simulator "flew" closer to the real thing than theirs! At their request I participated in their MMU upgrade, discovered that they had made some simplifying assumptions that degraded performance, and gave them the necessary dynamical equations for the fix. I also used these simulators to create narrated videos of anti-satellite concepts for the US Congress. This work is documented in two USAFA Technical Reports.

**1981-1982: Developed optimal guidance method for low-thrust orbit transfer**.

For continuous, low-thrust Orbital Transfer Vehicles (space "tugboats") to be effective, a compact, onboard, guidance system is needed to efficiently move satellites. I broke the dynamics down into fast and slow time-varying parameters. This unique formulation allowed me to find an analytic solution for circle-to-circle transfers, dubbed the **Alfano Transfer.** This work was published in the **AIAA Journal of Guidance, Control, and Dynamics.** My co-author was my thesis advisor.

**JOURNAL REFEREE:**

AAS Journal of the Astronautical Sciences

Acta Astronautica

AIAA Journal of Guidance, Control, and Dynamics

AIAA Journal of Spacecraft and Rockets

Celestial Mechanics and Dynamical Astronomy

Committee on Space Research (COSPAR) Advances in Space Research

IEEE Transactions on Aerospace and Electronic Systems

Journal of Aerospace Engineering

**U.S. PATENTS:**

6694283 - Eigenvalue quadric surface method for determining when two ellipsoids share common volume for use in spatial collision detection and avoidance (with Chan & Greer).

7383153 - Method for determining maximum conjunction probability of rectangular-shaped objects.

8041509 - System and method of addressing nonlinear relative motion for collision probability using parallelepipeds.

8275498 - System and method for assessing the risk of conjunction of a rocket body with orbiting and non-orbiting platforms.

8494688 - System and method for detection of anti-satellite vulnerability of an orbiting platform.

10293959 - Probability and frequency of orbital encounters

10551994 - Probability of Collision Bounding Surfaces

10558320 - Probability of Collision Topology

**HONORS AND AWARDS:**

**AAS Fellow**, September 2012

**STK Certified Rocket Scientist,** Analytical Graphics, Inc., June 2004

**Inventor's Award,** The Aerospace Corporation, Dec 2003

**Inventor's Award,** The Aerospace Corporation, July 2001

**Wall of Fame,** Earl L. Vandermeulen High School, July 2000

**USAF Scientific Achievement Awards**, received 5 at Phillips Lab from Jul 92 - May 95

DOD Acquisition Professional Development Program Certifications

**Systems Planning, Research, Development, and Engineering, Level III,** 1994

Test and Evaluation, Level I, 1994, -- Program Management, Level I, 1995

**USAF Research and Development Award,** 1991

**AFSC Frank J. Seiler Award for Research Excellence,** 1989

**Distinguished Graduate**, AF Institute of Technology, 1982

**Distinguished Graduate**, Undergraduate Pilot Training, 1975

**Top Academic Award Recipient**, Undergraduate Pilot Training, 1975

**REFEREED PUBLICATIONS:**

1. "The technical challenges of better Space Situational Awareness and Space Traffic Management," with D.L. Oltrogge, *Journal of Space Safety Engineering*, Volume 6, Issue 2, May 2019, pp. 72-79, DOI: 10.1016/j.jsse.2019.05.00410.1016
2. "Volumetric assessment of satellite encounter rates," with D.L. Oltrogge, *Acta Astronautica*, Volume 152, 2018, pp. 891-907, DOI: 10.1016/j.actaastro.2018.09.030
3. "Probability of Collision: Valuation, Variability, Visualization, and Validity," with D.L. Oltrogge, *Acta Astronautica*, Volume 148, July 2018, pp. 301-316, DOI: 10.1016/j.actaastro.2018.04.023
4. "A comprehensive assessment of collision likelihood in Geosynchronous Earth Orbit," with D.L. Oltrogge, C. Law, A. Cacioni, T.S. Kelso, *Acta Astronautica*, Volume 147, June 2018, pp. 316-345, DOI: 10.1016/j.actaastro.2018.03.017
5. "On selecting satellite conjunction filter parameters", Acta Astronautica, Vol. 99, June-July 2014, pp. 193–200. DOI: 10.1016/j.actaastro.2014.02.004.
6. "Eliminating Assumptions Regarding Satellite Conjunction Analysis", AAS Journal of the Astronautical Sciences, Vol. 59, Issue 4, December 2012, pp. 676–705.DOI: 10.1007/s40295-014-0002-4.
7. "Curvilinear coordinate transformations for relative motion," with D.A. Vallado, Celestial Mechanics and Dynamical Astronomy, Vol. 118, Issue 3 (March 2014), pp. 253-271. DOI: 10.1007/s10569-014-9531-1.
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44. "ComSpOC Update and Operational Benefits," With D. Oltrogge, 31st Space Symposium, Technical Track, Colorado Springs, Colorado, U.S.A., April 13-14, 2015.
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47. "Operating Characteristic Approach To Effective Satellite Conjunction Filtering," With D. Finkleman, Paper No. AAS 13-435, AAS/AIAA Space Flight Mechanics Meeting, Kauai, Hawaii, February 10 – 14, 2013.
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52. "Advances in Satellite Conjunction Analysis," With Robert Hall and Alan Ocampo, Advanced Maui Optical and Space Surveillance Technologies Conference 2010, Wailea, Maui, Hawaii, September 14-17, 2010.

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63. "Collision Avoidance Maneuver Planning Tool," Paper No. AAS 05-308, 15th AAS/AIAA Astrodynamics Specialist Conference, Aug 7-11, 2005.
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**PROFESSIONAL ASSOCIATIONS:**

American Institute of Aeronautics and Astronautics (AIAA) (**Associate Fellow**)

**Member of AIAA Astrodynamics Technical Committee** (Feb 93 – May 98)

**Chairman of Publication Committee** (Aug 93 - May 96)

**Chairman of AIAA Astrodynamics Technical Committee** (May 96 – May 98)

**Member of AIAA Astrodynamics Standards Committee** (Aug 96 - Aug 99)

American Astronautical Society (AAS) (**Fellow**, as of 27 September 2012)

**Member of AAS Spaceflight Mechanics Committee** (Feb 93 – Aug 98)

Tau Beta Pi (Engineering Honor Society)

USAFA Association of Graduates

The Military Officers Association of Americ