Adventures as an Applied Mathematician at The Aerospace Corporation

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June 25, 2021

Approved for public release. OTR 2021-00540.

The Aerospace Corporation

Created in 1960 as a California nonprofit corporation

Governed by Board of Trustees

- Operates a Federally Funded Research and Development Center (FFRDC) sponsored by the Air Force
- Staff & Budget (2020 Annual Report)
  - *4166 people (~3200 technical staff)*
  - *Average Technical Years of Experience: 25.6 years*
  - *FY20 Revenue $1.15 Billion*
  - *Major Locations in El Segundo, CA; Albuquerque, NM; Colorado Springs, CO; Chantilly, VA; and Washington D.C.*

> *The nation's trusted partner, solving the hardest problems for the preeminent space enterprise."*

The Aerospace Corporation

- Operates a FFRDC for the Department of Defense (DOD) focused on National Security Space
  - *Established in 1960 to oversee space and missile programs for the U.S. Air Force*
  - *Nonprofit, independent organization, free from conflict of interest*
  - *Customers: U.S. Air Force Space & Missile Center (SMC) and National Reconnaissance Office (NRO)*
  - *Mission also includes Civil & Commercial programs, such as NASA, National Oceanic and Atmospheric Administration, Law Enforcement, Federal Aviation Administration (FAA)*

- Highest Technical Degree:
  - *25% Ph.D*
  - *45% Master of Science*
  - *23% Bachelor of Science*
- Discipline of Highest Technical Degree
  - *Mechanical & Aeronautical Engineering: 29 %*
  - *Electrical Engineering: 21 %*
  - *Physics: 6%*
  - *Computer Science: 15 %*
  - *Mathematics: 4 %*
  - *Civil, Chemical, & General Engineering: 4 %*
  - *Chemistry: 3 %*

There are 4166 regular employees which include around 3200 Members of the Technical Staff (MTS).

Over 400 employees have Mathematical Scientist Degrees, including Computer and Informational Sciences & Cyber Security degrees

My current department, Radar Processing & Analysis, includes specialists in Physics, Electrical Engineering, Applied Mathematics, and Systems Engineering. (PhD & Master's levels)

Statistics extracted from the Aerospace 2020 Annual Report

Website: www.aerospace.org

Where does Aerospace fit in?

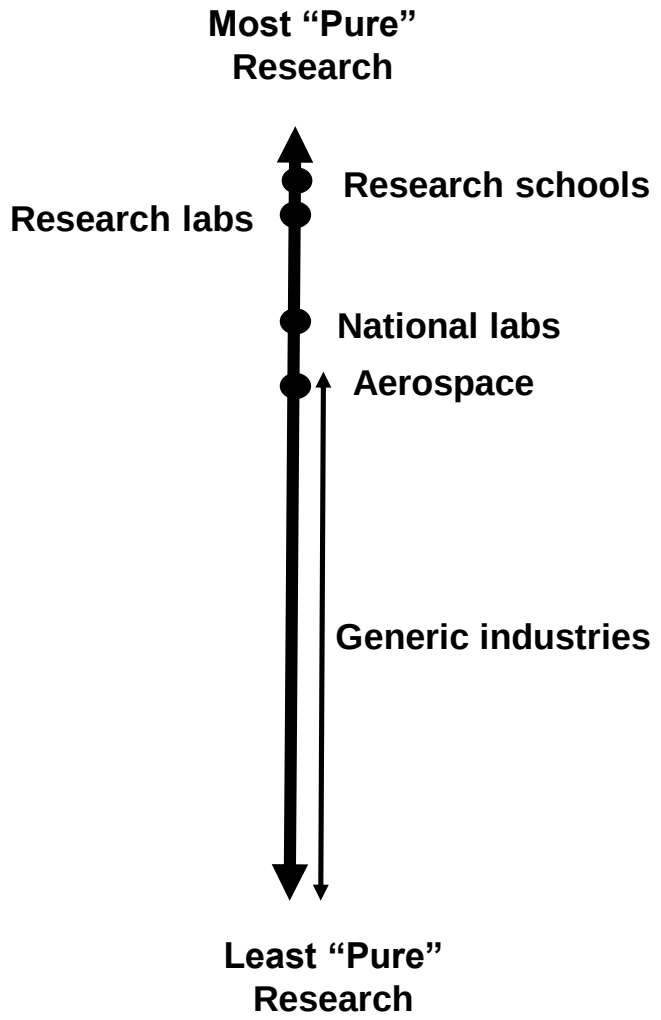
The mathematics employment notional spectrum

Academia: Universities & Colleges

National Labs: Sandia, Livermore, Los Alamos, etc.

FFRDC & Not-for-Profit Company: Aerospace Corporation

Industry: For-Profit corporations like Boeing, Northrop, Exxon, etc.



Applied & Pure Research efforts differ in definition, priority, and level of funding for different types of workplaces.

What Does Aerospace Do?

We Provide Technical and Analytical Expertise to Space Programs in Service of the National Interest

- **Concept development**
  - *Assist DoD to rough out space concepts prior to contractor selection*
- **Contractor selection**
  - *Provide technical assistance to DoD as it selects a contractor*
- **Development oversight**
  - *Evaluate/assist the contractor during development*
  - *Overview component/subsystem/system testing*
- **Launch/early orbit assistance**
  - *Assist contractor/government team during launch and early orbit operations*
- **Operations and anomaly assistance**
  - *Provide as-requested services*
- **End-of-life operations**
  - *Help determine end–of-life status, orbit removal*

Aerospace includes technical laboratories that our sponsors rely upon, within the contexts of both development and anomaly mitigation.

Aerospace's involvement with GPS spans its complete life cycle.

The 1st Aerospace President, Dr. Ivan Getting is recognized as a co-inventor of GPS.

My Background/Career

- Education:
  - *Ph.D. in Applied Mathematics specializing in Numerical Analysis, UCLA.*
  - *MS in Applied Mathematics from Purdue University.*
  - *BS in Mathematics from Bucknell University.*
  - *I had planned to follow a traditional academic career path, but I was waylaid first by the two-body career problem and second by the enjoyment I derived from working on algorithms, modeling & simulations.*
- Job Experience
  - ***The Aerospace Corporation**: I have worked primarily in Aerospace's Engineering & Technology Group (ETG), but I also have worked for a Program Office.*
  - *I have worked here for over 40 years, starting as a Member of the Technical Staff in the Trajectory Analysis & Programming Dept, promoted to Engineering Specialist in the Flight Mechanics Department, and then transferred mid-career to the Radar Processing & Analysis Department.*
  - ***UCLA**: Visiting & Adjunct Lecturer Positions. Teaching graduate level Numerical ODEs, and undergraduate calculus classes*
- Society for Industrial & Applied Mathematics (SIAM) Activities
  - *Currently serving on the Board of Trustees, but have also served on the SIAM Council, and multiple SIAM committees*

My Career objective has been to work on interesting & challenging real-world problems, that require developing, implementing, and utilizing mathematical algorithms. "Applied Research" is required to create robust & useful & efficient algorithms. Access to world class data is exciting!

Overview of Career Projects

- Trajectory Simulation, Modelling & Optimization
  - *Numerical Integration Methods*
  - *Least Squares Cubic Spline Smoothing of 1962 U.S. Standard Atmosphere Data*
  - *Exploitation of Sparsity in Generalized Reduced Gradient Optimization Algorithm*
- Synthetic Aperture Radar (SAR): Processing and Algorithms
  - *SAR Image Processing Chain*
    - Autofocus Algorithms
  - *Image Quality Metrics*
    - Metrics for Impulse Responses (IPRs): Widths, Legendre Figures of Merit, PSLR, Sharpness
    - Semi-Automated Algorithm for estimating the Terrain-to-Noise Ratio (TNR) Metric
  - *Super Resolution*
  - *Performance Modelling of Requirements*
  - *Simple Example of "Making a Difference"*

Synthetic Aperture Radar (SAR)

Processing of the Phase History Data to an Imagery Product: starting with complex-valued measurements (phase & amplitude), there are many interesting algorithms involved in order to apply the needed compensations.

Phase History Analysis, Motion Compensation, Autofocus Algorithms

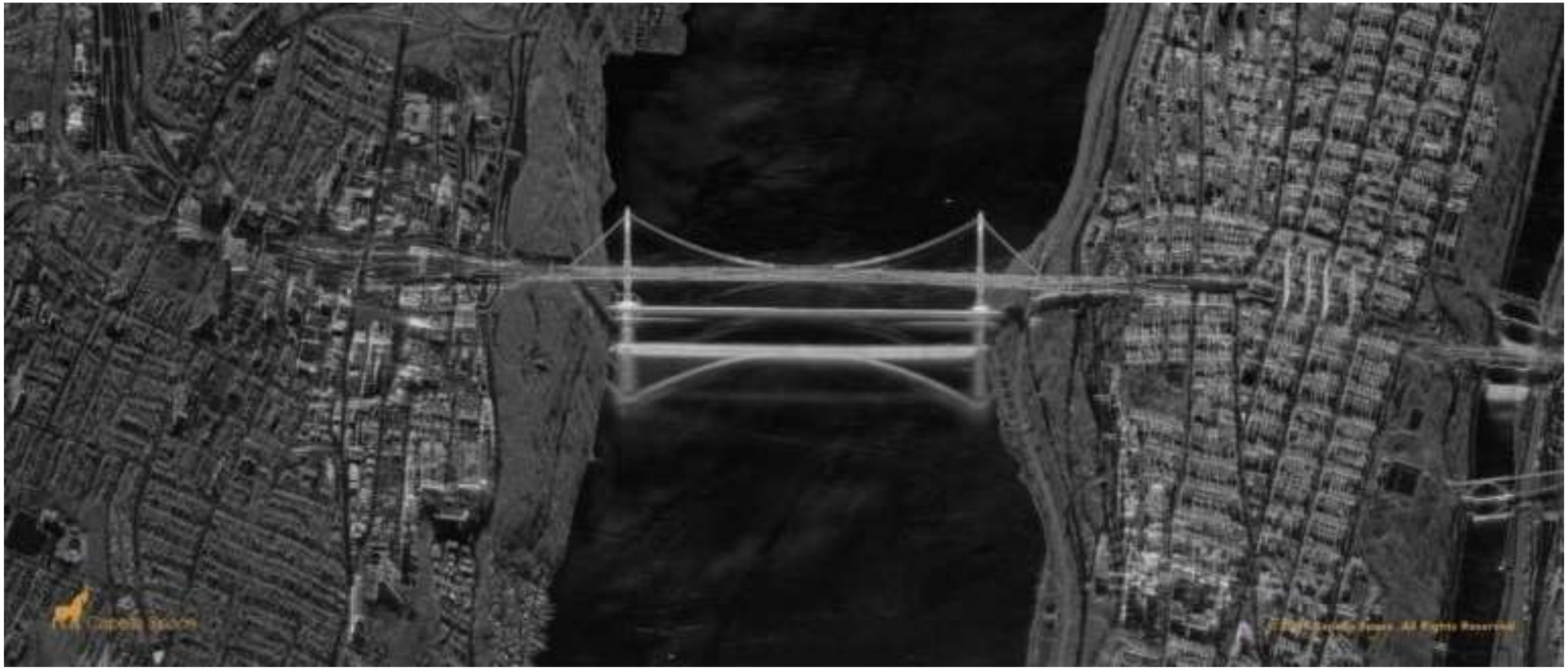
Life Cycle of a SAR System:
Design of SAR Sensor
Requirements Analysis
Building the SAR (Timeline Analysis): ground testing/ testing the sensor operation/ IPR testing/ ground software testing
SAR On-orbit Initialization: Image Quality checkout
Anomalies & End of Life issues

Capella Space
Home - Capella Space

Palm Jumeirah, Dubai
Released in SPACE NEWS
on Oct 7, 2020

Capella Space

Capella Space
Home - Capella Space



“The advent of commercial space has created a wealth of information from a new generation of low Earth Orbit satellites. Capella Space is the first U.S. company to bring that data back to Earth to help humanity obtain a clear and accurate picture of the planet with Synthetic Aperture Radar (SAR).”

Evolution of Algorithms & Software Development

- Algorithm Development
  - *Formulate a mathematical model of the physical process of interest.*
  - *Develop an algorithm, possibly using simulated data.*
  - *Later the algorithm is "matured" as it is applied to the actual data, as sometimes original assumptions & algorithm are found to be deficient.*
  - *Alternate algorithms are evaluated along the way as this process forces all algorithms to improve.*
- Software Development
  - *First prototyped in a language such as Matlab, Python, MathCad, or IDL.*
    - Integrates computation, visualization & programming in a flexible environment.
  - *Production codes often written in Fortran, C, or C++ .*
- Measurable quality metrics improvements are important to this process.
- Life cycle of development for algorithms may be short or long.
- As new applications for each algorithm are discovered, the algorithm matures.
- Ultimately, a successful algorithm will be 'adopted' by the customer and implemented into "operations" by contractors.

Some Other Considerations

Measuring Success: What is important to you?

- Position on Corporate Ladder
  - *Management Paths: Director, Principal Director, General Manager, VP*
  - *Technical Paths*
    - ETG: MTS, Engineering Specialist, Senior ES, Principal Engineer
    - Program Offices: Project Engineer, Project Leader, Senior PE & PL
    - Labs: Research Scientist, Senior RS, Principal Scientist
    - Distinguished Engineer
- Salary
- Peer Recognition (internal & external to employer)
- Technical Achievements
- Publishing Record
- Tenure in Academia
- Balancing Career & Home Life

Parallels to Careers in Academia

- Work on interesting real-world challenging problems (“solving your Customer’s problems”)
- Briefings to Customers at Technical Exchange Meetings (i.e., “giving talks”)
- Research & Writing Grant proposals (IRADs and Engineering Methods Proposals)
- Participate in Conferences (IEEE, SIAM, etc)
- Reviewing Papers, Briefs, Competing Contractor Methods & Proposals
- Writing: Publishing journal papers or classified reports
- Mentoring new hires
- Teaching internal classes for The Aerospace Institute
- Community Service Opportunities: outreach programs to schools

Skills needed to work in industry

- Communication and small group skills
  - *Written/interpersonal/public speaking*
- Mathematical agility **(Can you move around?)**
- Mathematical maturity **(Can you do the job?)**
  - *Ability to abstract physical/engineering problems*
  - *Ability to solve those problems*
- Exposure to physical and engineering sciences
- Computer programming
- You are unlikely to find a job description calling for a “mathematician”
- Use insider information (Whom do you know?)
- Apply whether you think you’re qualified or not

Aerospace has a Summer Internship Program.

Observations

- You do not have to have a PhD to advance up the corporate ladder (but it helps)
- There is no “Mathematics Department”
- MTS with Math degrees are dispersed throughout the Program offices and ETG (a few clusters in ETG)
  - *Systems Engineering and Computer Systems divisions*
  - *Electronic Systems*
- Typically, each individual has carved his own niche where he/she can pursue their own technical and management
- Expect to work in a team environment with engineers and scientists
- Past President and CEO of The Aerospace Corporation: Dr. Wanda Austin
  - *She has a B.A. in mathematics from Franklin & Marshall*
  - *M.S. degrees in mathematics and systems engineering from*
  - *U. of Pittsburgh, and a Ph.D. in Systems Engineering from USC*
  - *Started as a Level 1 in ETG.*

SIAM

Society for Industrial & Applied Mathematics

- Premier Applied Mathematics Organization
- Student Resources (www.siam.org)
  - *Student membership (discounted or FREE)*
  - *Student Chapters*
  - *Research Opportunities/ Fellowships*
  - *Job Search Resources*
  - *Links to Summer Research/Workshop opportunities*
  - *Student Travel awards to conferences*
  - *Publishes SIAM Newspaper, Journals, and books*
- Networking!
  - *Links to industry, academia, and funding organizations (NSF, etc.)*

Stay connected! Nourish your expertise (depth & bread of knowledge) by staying involved with academia, national labs, and other related industries.

Conclusions/ Summary

What Do I Hope You Have Learned?

- Mathematics plays an essential role in industry
- Mathematicians must absorb collateral disciplines
- Success requires agility, mathematical thinking
- Solution implementation can often be challenging

- Questions?