Boeing Technology
Phantom Works

A Career in Statistics

Fritz Scholz
Boeing Phantom Works & UW

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Biographical Sketch

- 1963-66: Studies of Mathematics & Physics
  at the University of Göttingen, Germany $\Longrightarrow$ Prediploma $\approx$ BA/BS

- On a lark applied for a VW scholarship.
  Was told to aim for Statistics since Mathematics could be studied
  equally well in Germany, whereas Statistics was hardly represented there.

- 1966-71: Studied Probability & Statistics
  at the University of California, Berkeley $\Longrightarrow$ Ph.D. in Statistics

- Taught at Berkeley 1971-72, at the UW Mathematics Department 1972-78.

Biographical Sketch (contd.)

- In 1978 joined the Applied Statistics Group at Boeing Computer Services which ultimately transformed into Boeing Phantom Works after the merger with McDonnell Douglas.

- UW Affiliate (Associate) Professor of Statistics since (1980) 1992

- Boeing Technical Fellow in 1991,

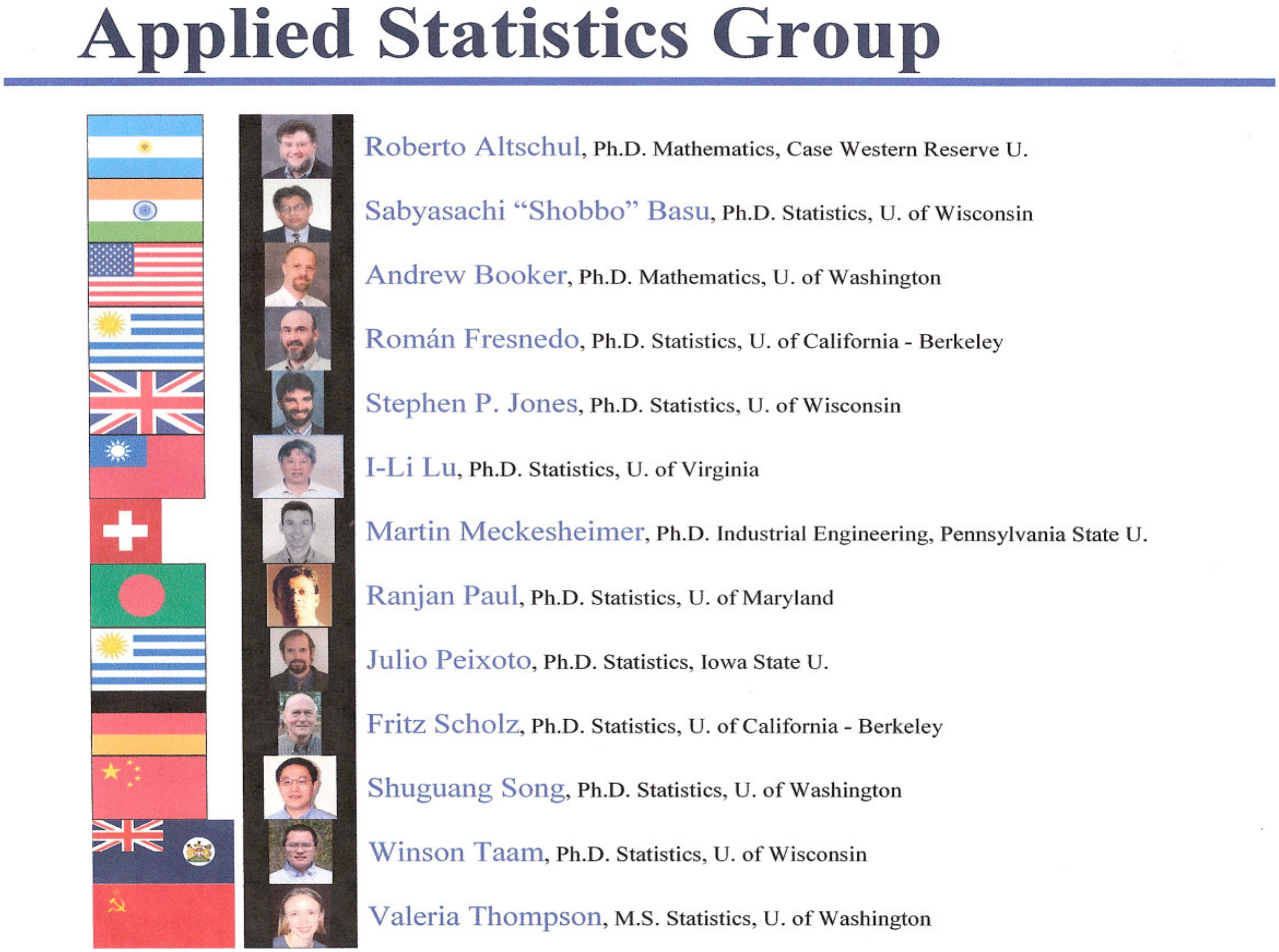
- Fellow of the American Statistical Association in 1997

MEA / The Boeing Math Group

Mathematics & Engineering Analysis (MEA)
is culturally very diverse/international and consists of

- Mathematical Modeling [16] (the Engineering side)
- Applied Statistics [13, 12 PhDs]
- Operations Research [13]
- Computational Mathematics [17] (Differential Equation & Linear Algebra)
- Modeling & Simulation Technology [25]
- Geometry & Optimization [17]

Diversity



Applied Statistics Group

Roberto Altschul, Ph.D. Mathematics, Case Western Reserve U.
Sabyasachi “Shobbo” Basu, Ph.D. Statistics, U. of Wisconsin
Andrew Booker, Ph.D. Mathematics, U. of Washington
Román Fresnedo, Ph.D. Statistics, U. of California - Berkeley
Stephen P. Jones, Ph.D. Statistics, U. of Wisconsin
I-Li Lu, Ph.D. Statistics, U. of Virginia
Martin Meckesheimer, Ph.D. Industrial Engineering, Pennsylvania State U.
Ranjan Paul, Ph.D. Statistics, U. of Maryland
Julio Peixoto, Ph.D. Statistics, Iowa State U.
Fritz Scholz, Ph.D. Statistics, U. of California - Berkeley
Shuguang Song, Ph.D. Statistics, U. of Washington
Winson Taam, Ph.D. Statistics, U. of Wisconsin
Valeria Thompson, M.S. Statistics, U. of Washington

M&CT: Home of MEA

- MEA
- Computing Systems Technology
- Intelligent Information Systems
  - Home of Data & Text Mining
  - a separate Statistics group with special focus

Application Areas

- Commercial Aviation

  707, 717, 727, 737, 747, 757, 767, 777, and next up 787

- Military Aviation

  Bombers, fighter jets, transport planes, helicopters

- Space

  Space Shuttle, International Space Station, rockets

- Outside commercial business

  DOE, NRC, NASA, EPRI, AT&T etc.

Wide Spectrum of Statistical Problem Areas

- data mining
  (Data from manufacturing, business processes,
  airline operations and maintenance $\Longrightarrow$ improve efficiency)

- statistical quality & process control
  (Boeing internal & interfacing with suppliers)

- design of experiments
  (making most effective use of expensive experimental units
  through fractional factorial designs)

- design & analysis of computer experiments
  (using expensive computer models efficiently for best design)

Wide Spectrum of Statistical Problem Areas

- reliability & risk analysis (high reliability through redundancy design, analysis of lifetime data, assess significance of incidents, constant vigilance, 10^{-9} an industry standard, software reliability)

- statistical tolerancing & metrology (engineering/manufacturing tolerances, measurement system calibration, accuracy Assessment)

- interaction with regulatory agencies (FAA, NTSB, ICAO, MIL-HDBKs)

A Guiding Principle: Academia vs Industry

- the task is to find a path from **A** to **B**

- after considerable effort one finds that a path to **C** is easier & elegant

- this works fine for academic publishing since nobody insists on the goal **B**.

- In Industry you Keep your Eye on **B**,
  and Achieve it by whatever Hop, Skip, and Jump Method
  Possibly not an Airtight Argument,
  but Supported by Simulations and other Checks

- This is Usually not Elegant or Publishable, often Proprietary

Some of my Projects over Time (1)

- Power Grid Behavior during Outages [Random Loads] (Customer: DOE)
- Detection of Electric Power Theft [Consumption Patterns] (Customer: EPRI)
- Detection of Nuclear Material Diversion [Measurement Error] (Customer: NRC)
- Develop Sampling Methodology for AT&T [AT&T Breakup]
- Meteoroid and Space Debris Risk Assessment for ISS (Customer: NASA)
- Software Reliability, Reliability Growth [Bug Removal] (Customer: NASA)
- Engine Shut-Downs in Relation to Flight Hours & Cycles

Some of my Projects over Time (2)

- Aircraft Accidents in Relation to Crew Size (2 vs 3, Simpson's Paradox)
- Lightning Risk Assessment, A6 Re-Wing Program (Attachment Points)
- Uncertainty Model for Exterior Aircraft Noise (Noise Allowance Trade-off)
- Bayesian and Evidential Reasoning for Sensor Blending (Target Recognition)
- Calibration Curves for Boeing Metrology Lab
- Useful Life Extension Program of IUS Program (Cracks in Solid Rocket Motors)
- Setting Guarantees for Interior Aircraft Noise (Random Curves)

Simple Recipe for Random Curves

$Y_1, \ldots, Y_k$ iid $\sim \mathcal{N}(\mu, \sigma^2)$ (normal random sample)

How to generate a new $Y^\star$ using estimated parameters $\bar{Y}$ and s^2 ?

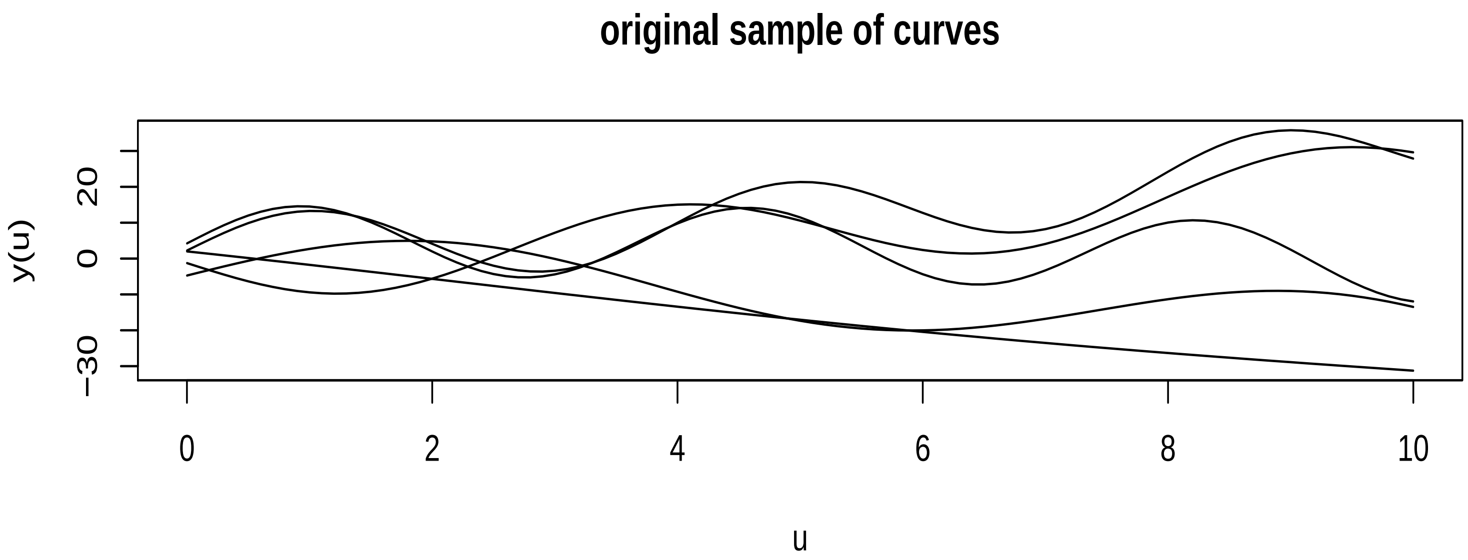
Generate $Y^\star$ from $\sim \mathcal{N}(\bar{Y}, s^2)$ or

$$Y^\star = \bar{Y} + \sum_{i=1}^{k} w_i (Y_i - \bar{Y}) \qquad \text{with } w_i \text{ iid} \sim \mathcal{N}(0, 1/(k-1))$$

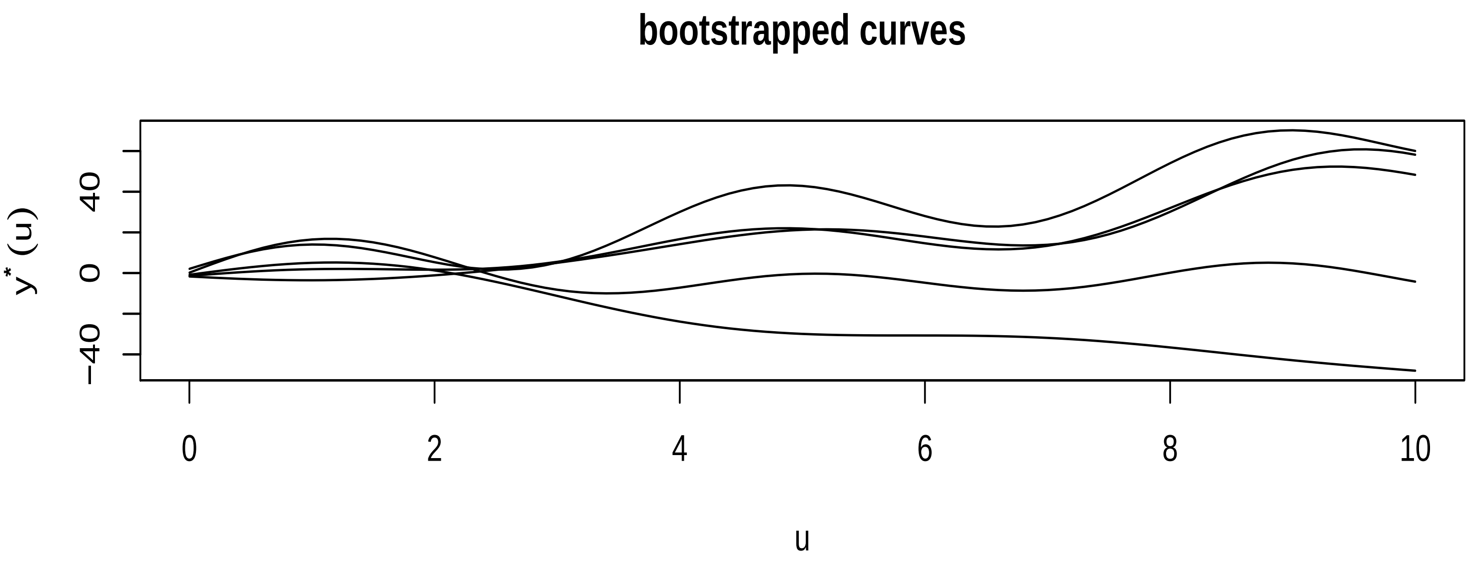
Extend to curves $Y_i(u),\ i = 1, \ldots, k$ by generating

$$Y^\star(u) = \bar{Y}(u) + \sum_{i=1}^{k} w_i (Y_i(u) - \bar{Y}(u)) \qquad \text{with } w_i \text{ iid} \sim \mathcal{N}(0, 1/(k-1))$$

Random Curves



original sample of curves

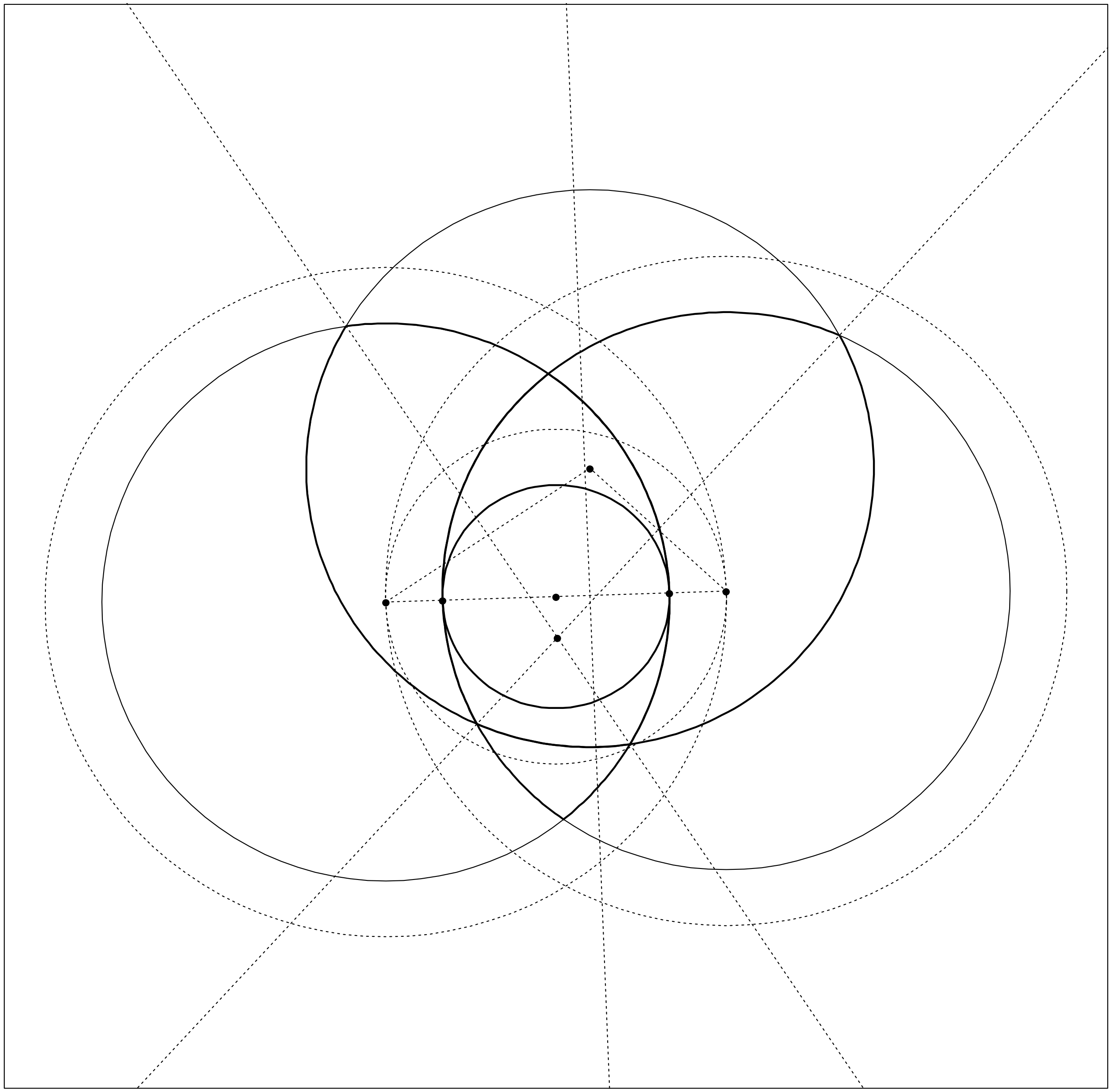


bootstrapped curves

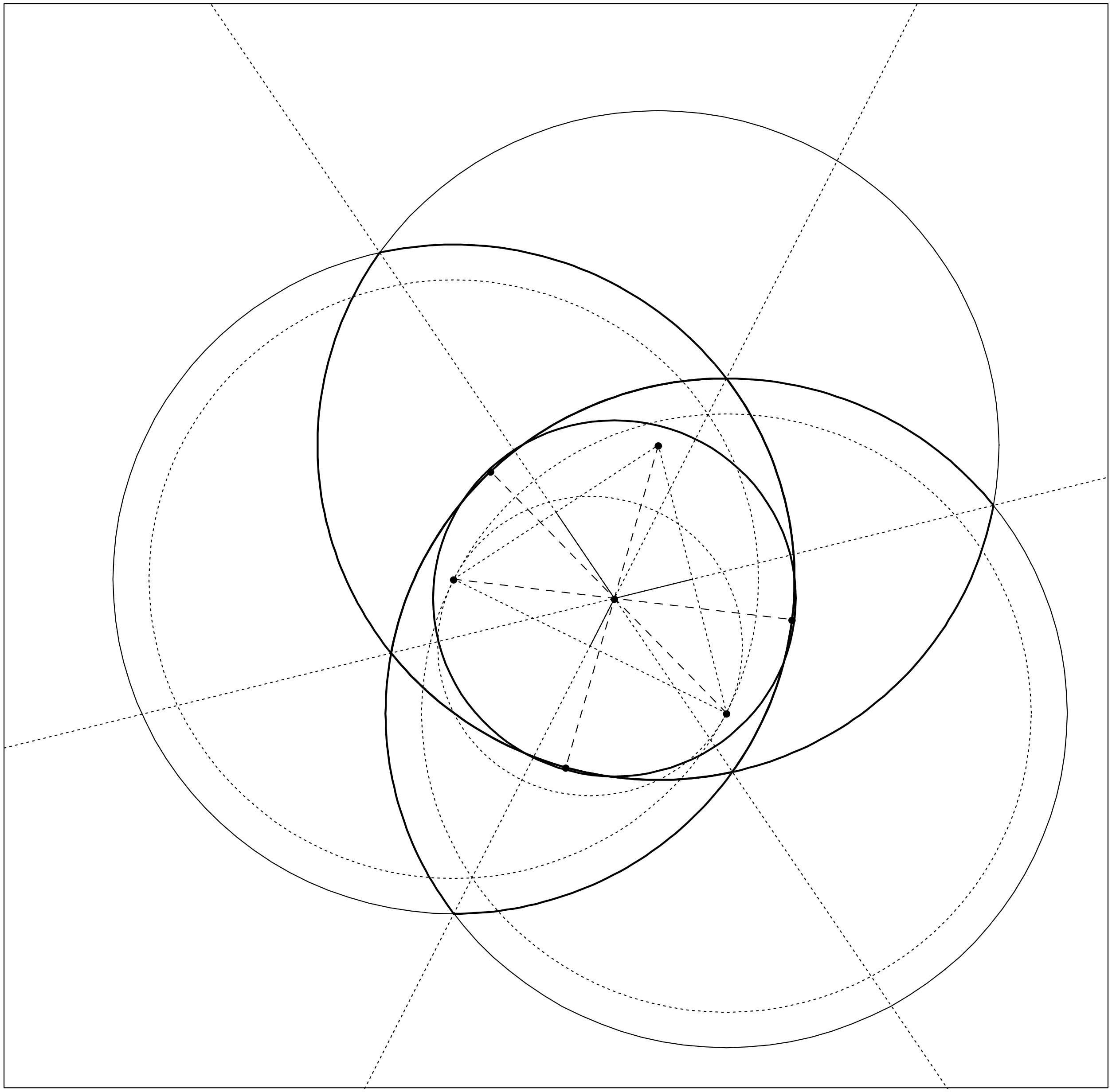
Some of my Projects over Time (3)

- Teaching Regression, Weibull and Tolerance Analysis to Boeing Engineers
- AUTOLAND Sinkrate Risk Assessment (Nonparametric Tail Extrapolation)
- Quality Control Problems under Nonstandard Conditions
- Salary Curve Fits for Corporate HR (Salary Planning, Industry Comparison)
- Tolerance Analysis of Interchangeable Cargo Door Hinge Lines (Not RSS)
- Tolerance Analysis to Assess Hole Positioning Requirements for Fuselage Assembly (Inside Diameter of 3 Intersecting Circles)

Inside Diameter of 3 Intersecting Circles I



Inside Diameter of 3 Intersecting Circles II



Some of my Projects over Time (4)

- Statistical Tolerancing for Fuselage Assembly Modeling,
  Collaboration with IBM (Disk Drives)
  and Boeing Wichita ATA Program $\Longrightarrow$ Patent: Statistical Tolerancing

- Provide Statistical Expertise as Part of Air India Litigation (Vertigo, Horizon)
  and Alaska 261 Crash (Jack Screw)

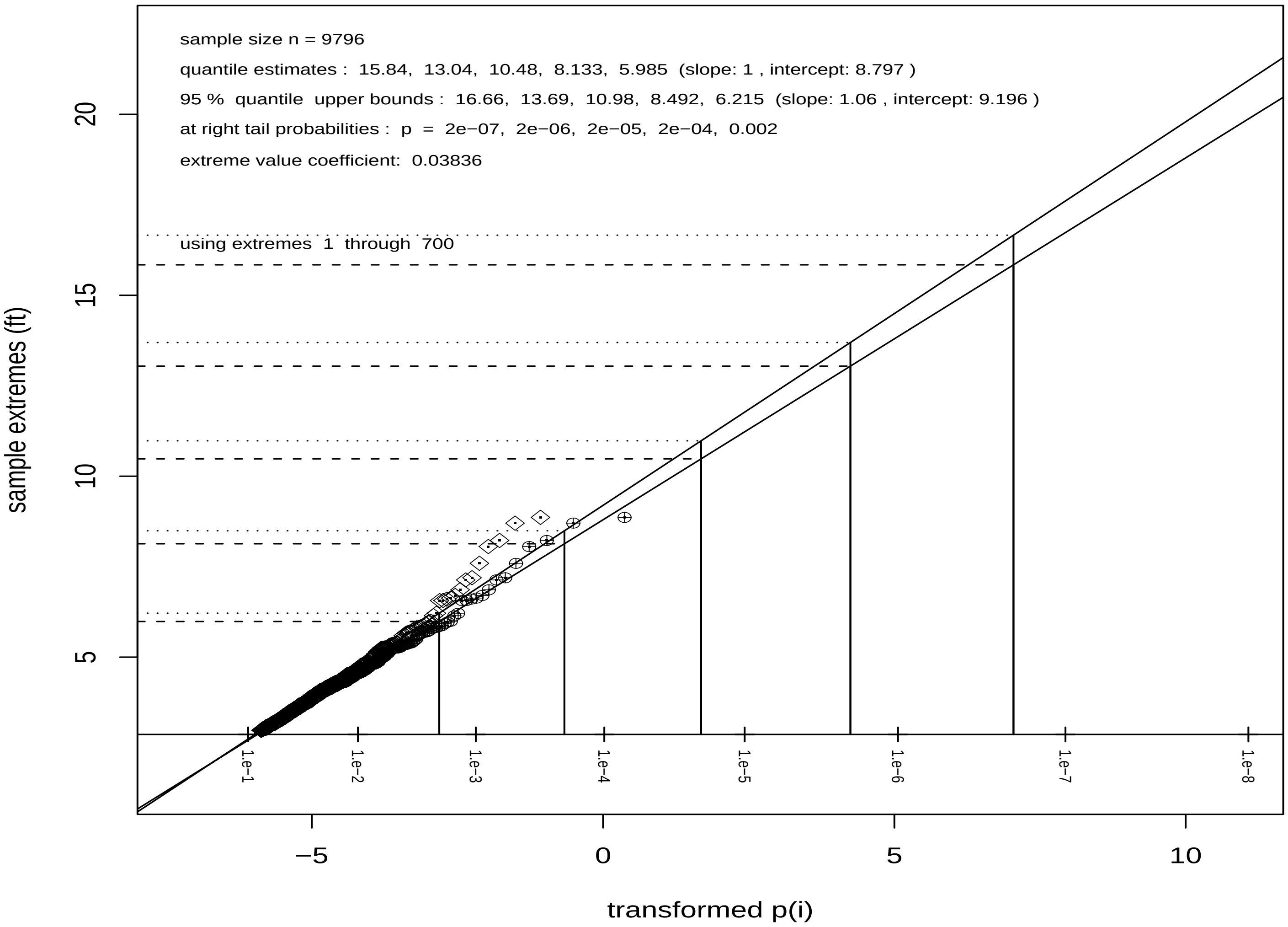
- Risk Analysis for Space Shuttle Solid Booster Rocket Bolt Hang-up Problem

- Risk Assessment for the CH-47 Helicopter Fleet due to Rotor Blade Swirls

- Taxiway Centerline Deviations for 747 (Joint Research with FAA)
  Extreme Value Behavior, Separation of Taxiways, Taxiway Widths,
  Implications for A-380, Support FAA in Dealing with ICAO

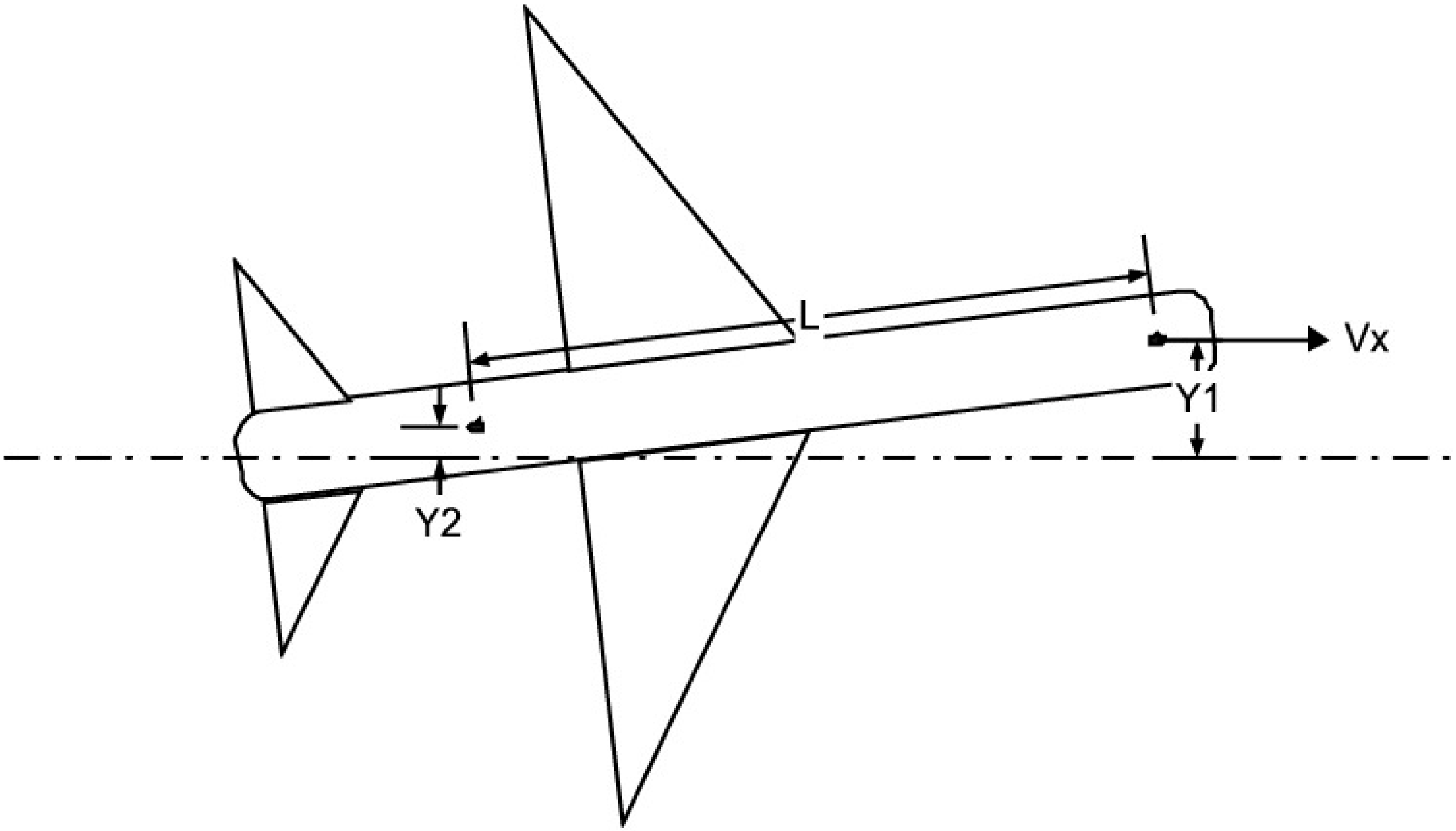
Taxiway Deviation Measurement by Laser ANC

Extrapolation of 747 Absolute Deviations



Nonparametric Extrapolation

Wandering Aircraft on Taxiway



Nose Gear to Main Gear Forced Sinusoid

Assume the Distance between Nose Gear Centroid and Main Gear Centroid is L.

If the Nose Gear Deviation $Y_1(t)$ from Centerline is a Sinusoid

$$Y_1(t) = \Delta + A\sin(2\pi t/T + \theta)$$

then the Main Gear Deviation $Y_2(t)$ Follows a Sinusoid with Same Frequency (in Steady State)

$$Y_2(t) = \Delta + A'\sin(2\pi t/T + \theta + \varphi)$$

with

$$A' = \frac{A}{\sqrt{(2\pi L/TV)^2 + 1}} \quad \text{and} \quad \varphi = -\arctan(2\pi L/TV)$$

V is the Aircraft Velocity

Point-wise to Length-wise Maximum Deviations

Getting Nose Gear and Main Gear Deviations at Two or More Locations we can Fit a Sinusoid

Minimize a Least Squares Criterion over the Four Unknown Parameters

$\Delta \qquad A \qquad \theta$ and $\kappa = TV$

This would give some Idea how Much Further out Deviations could have been had we measured at the right point.

Some of my Projects over Time (5)

- Assess Small Sample Properties of Bootstrap Methology
  The Bootstrap Gave Wings to Statistics, Handling Almost All Problems
  Very Intuitive and Appealing to Engineers

- Develop Monotone Confidence Bounds for Weibull Analysis (Web Page Tool)

- Transfer Previous Results to Logistic Regression Analysis,
  Assessing Crack and Damage Detection

- Handle Hundreds of Hotline Calls

The International Space Station (ISS)

Space Rubble

Seattle Post-Intelligencer, Monday, June 27, 1994

Orbiting rubble could threaten space station

By William J. Broad, The New York Times

Dead satellites, shattered rocket stages and thousands of other pieces of man-made space junk speeding around Earth could destroy a planned international space station, and engineers are struggling to reduce the danger.

NASA estimates there is a 20 percent chance that debris could smash through the shield of the space station, an orbital outpost for the world’s astronauts, during its construction and expected 10-year life.

The station will have gear to maximize safety and interior hatches to let astronauts seal themselves off from areas that would lose air if shattered. But the overall risk of a catastrophe that would result in death or destruction of the craft is still estimated at roughly 10 percent.

Space Rubble

NASA officials say they are confident that the risk of penetration can be reduced, perhaps to 10 percent, making the risk of catastrophe about 5 percent. Although the design already calls for much shielding, more may be added, they say, even while conceding that such a remedy adds cost and weight to an already heavily laden project.

”We'll do whatever is necessary to get adequate safety,” NASA Administrator Daniel S. Goldin said in an interview. ”If we need more shielding, we'll put more up.”

But Goldin also acknowledged that danger is inevitable in space exploration.

”We'll never be able to guarantee total safety,” he said. ”We could have loss of life with the shuttle, and the station as well. If you want to guarantee no loss of life, it's better not to go into space.”

Still, a station designer, who spoke' on the condition of anonymity, said the bureaucracy was playing down the problem and courting disaster.

”The traditional design philosophy says the mission's catastrophic risk should not exceed a few percent,” the designer said. ”Now, they've got it in the range of 10

Space Rubble

percent. That violates due diligence. If you’re working in an uncertain environment, your bias should be on the side of safety.”

Bigger than a football field at 361 feet in length and 290 feet in width, the station would have a six member international crew to study Earth, the heavens and human reactions to weightlessness in preparation for lengthy voyages to Mars and beyond.

The United States, Europe, Japan and Canada are longtime partners in the project, and Russia joined recently. The outpost would cost American taxpayers $43 billion, including $11 billion already spent on design studies.

Assembly flights are scheduled to begin in late 1997 and end in 2002, after which the completed outpost is to be used for a decade or more.

The U.S. military has found about 7,000 objects in orbit, ranging from the size of a school bus to the size of a baseball. Smaller objects cannot easily be tracked by radar. Because of the enormous speeds of everything in orbit, a tiny flake of metal can pack the punch of an exploding hand grenade.

ISS Wall Design

- The Modules of the ISS Have a Double Wall Design
  - How thick should the walls be?
  - How much space between the walls?
  - What material?
  - Other design factors.
- Risk of Penetration by Meteoroids and Space Debris
- Objective: Minimize Penetration Risk Subject to Economic Considerations
- Thicker Walls Lead to Heavier and More Costly Payloads.

The Poisson Process Probability Model

- The Poisson Process Provides a Very Useful and Appropriate Model for Describing the Probabilistic Behavior of Random Events over Time

- The Events are the Impacts by Space Debris and Meteoroids

- Flux or Intensity of Impacts per Surface Area per Year is a Driving Factor

- Penetration Factors of Impacting Object
  - Mass/Size, Velocity, Impact Angle of Objects
  - Wall Design

The Poisson Process

- The Poisson Process $N(t,A)$ Gives the Number of Random Impact Events on a Surface Area A during the Interval $[0,t]$, for any $t > 0$.

- $P(N(t,A)=k) = \exp(-\lambda tA)(\lambda tA)^k/k!$ for $k = 0,1,2,3,\ldots$

- $\lambda > 0$ is the Event Intensity Rate per Unit Area (m^2) & per Unit Time (Year).

- $1/\lambda$ is the Average or Expected Time between Events per Unit Area, $\lambda = 10^{-3} \Longrightarrow$ on Average 1 Event per 10^3 Area $\times$ Time Units ($m^2 \times$ Years).

- The Probability of Seeing at Least One Event on Surface Area A during the Mission Interval $[0,T]$ is $P(N(T,A) > 0) = 1 - P(N(T) = 0) = 1 - \exp(-\lambda TA)$.

A Thinned Poisson Process

- For Each Event of a Poisson Process $N(t,A)$ an Independent Trial Determines whether it is a Penetration Event.
- If $p =$ Probability of a Penetration Event, then the Resulting Process $N^\star(t,A)$ of Penetration Events over Area A during $[0,t]$ is again a Poisson Process with Intensity Rate $\lambda^\star = p\lambda$.
- This is Called a Thinned Poisson Process because Events are Disregarded or Thinned out with Probability $1-p$.
- The Resulting Risk of Seeing at least one Penetration Event on Surface Area A during the Mission Interval $[0,T]$ is then $P(N(T,A)>0) = 1-\exp(-\lambda^\star TA)$

Finite Elements & Sums of Poisson Processes

- The ISS Surface was broken down into some $k = 5000$ Triangular Elements with Respective Areas $A_1, \ldots, A_k$

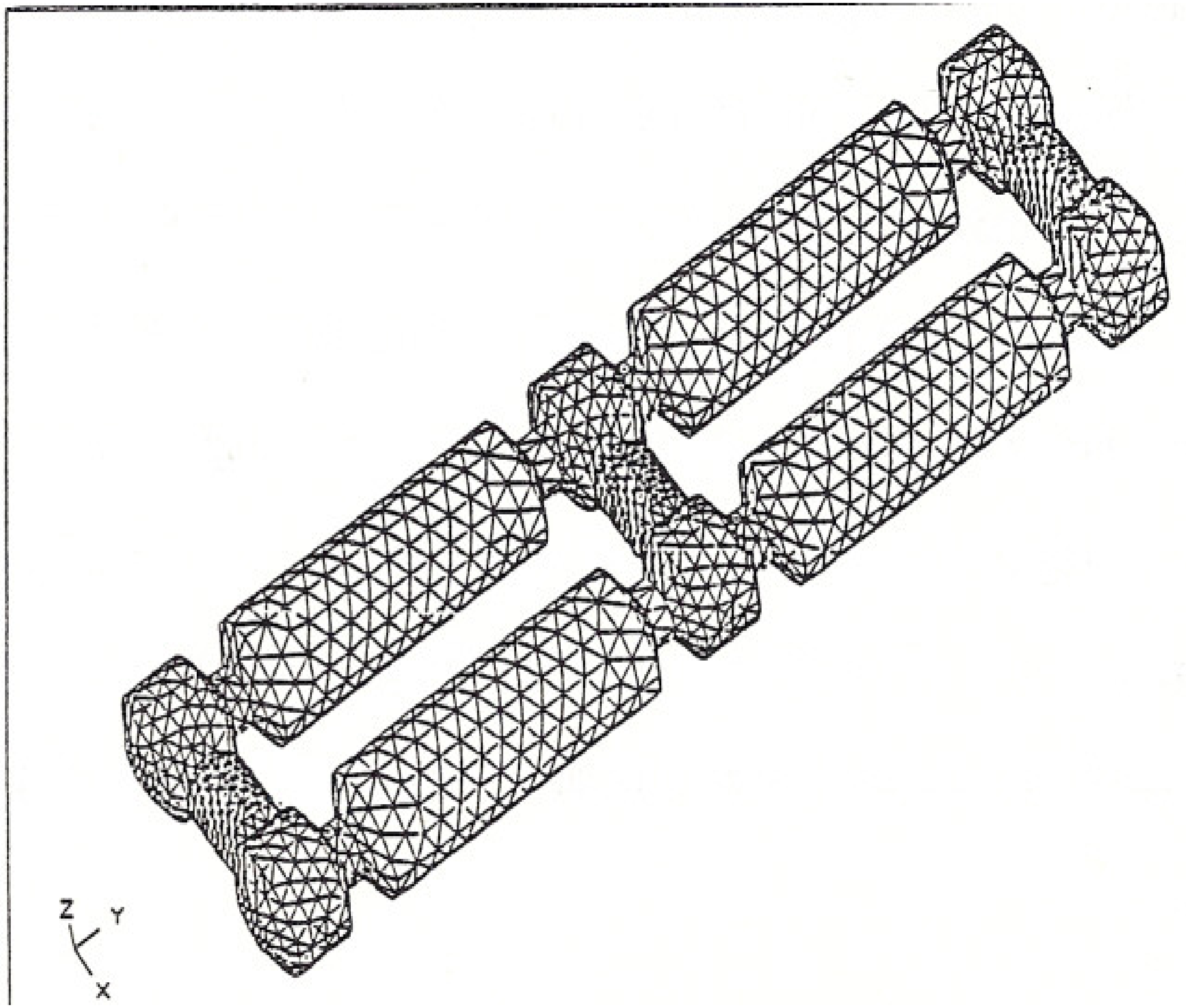
- Penetration Events for the k Surface Elements were Modeled by Independent Poisson Processes $N_i^\star(t)$, with Respective per Time Rates $\lambda_i^\star = p_i \lambda_i A_i,\ i = 1, \ldots, k$.

- $N_S(t) = N_1^\star(t) + \ldots + N_k^\star(t) =$ # of Penetration Events over Total Surface.

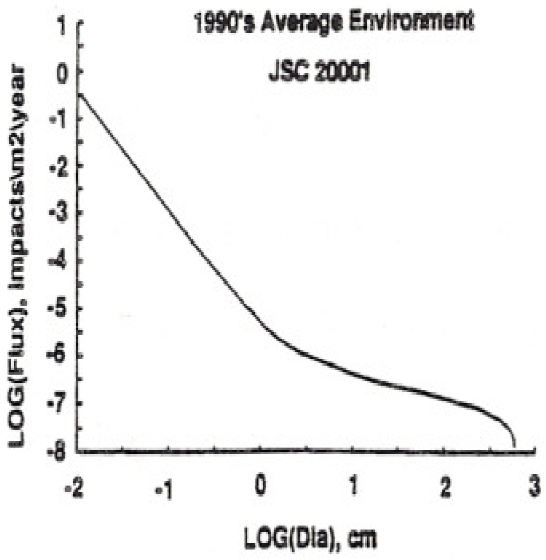
- $N_S(t)$ is a Poisson Process with Time Rate $\lambda_S = p_1 \lambda_1 A_1 + \ldots + p_k \lambda_k A_k$

  The Risk of at least one Penetration Event for the ISS during the Mission Interval $[0, T]$ is then $P(N_S(T) > 0) = 1 - \exp(-\lambda_S T)$

Finite Element ISS Surface Grid



Debris Size Flux Distribution



Flux Equation:

$\text{Log } F = -2.52 \text{ Log } D - 5.46$

D = diameter in centimeters; $D < 1.0$ cm

$\text{Log } F = -5.46 - 1.78 \text{ Log } D + 0.9889 (\text{Log } D)^2 - 0.194 (\text{Log } D)^3$

D = diameter in cemtimeters; $1.0 \text{ cm} \leq D \leq 200 \text{ cm}$

where:

F = Number of impacts of objects with diameter D or greater per square meter per year

Log = Logarithm base 10

Orbital Altitude = 500 km

Figure 2.1-1. Debris Flux Environment

Impact Angle Distribution

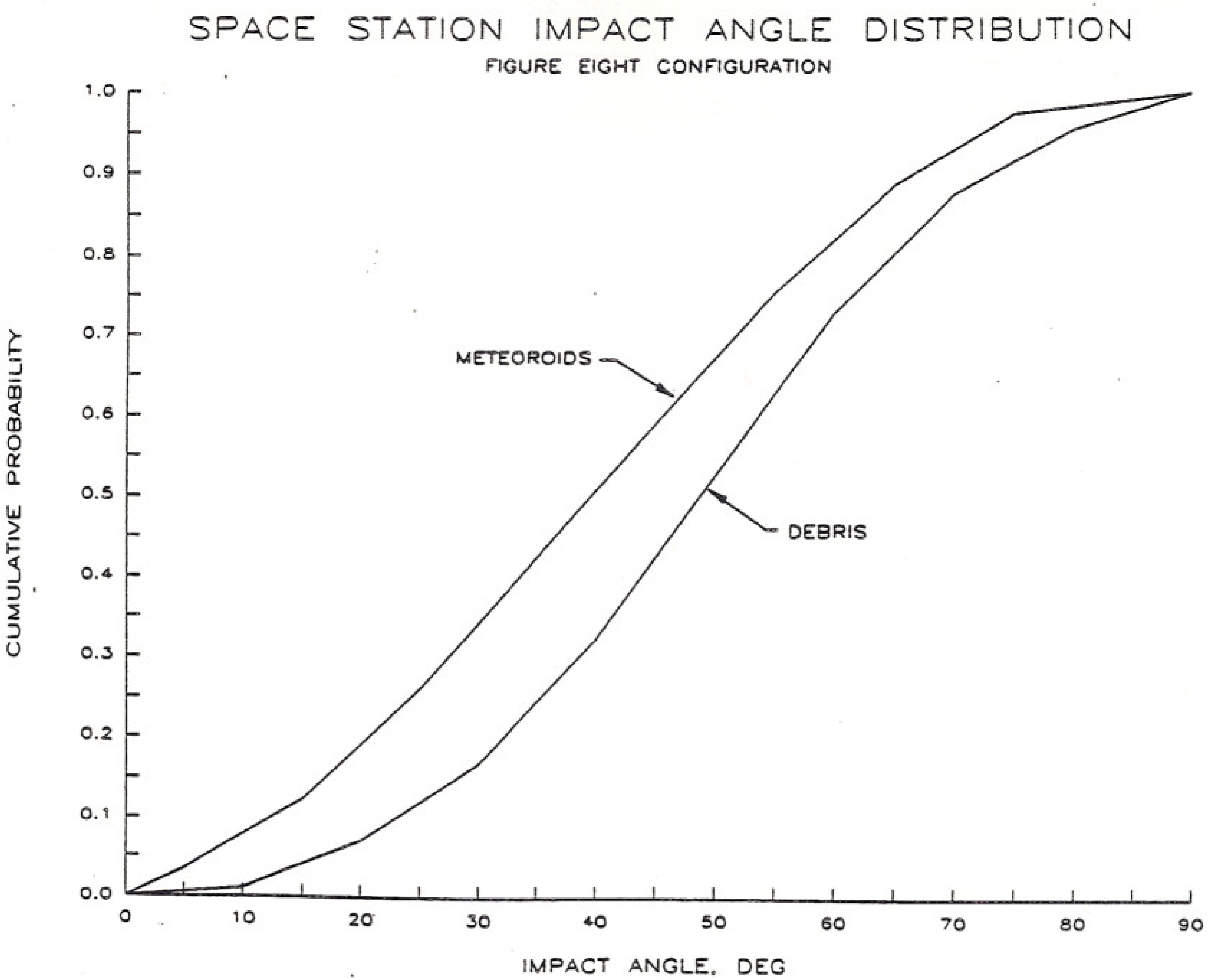


Figure 2.8-1. Impact Angle Probability Distribution

Meteoroid Velocity Distribution

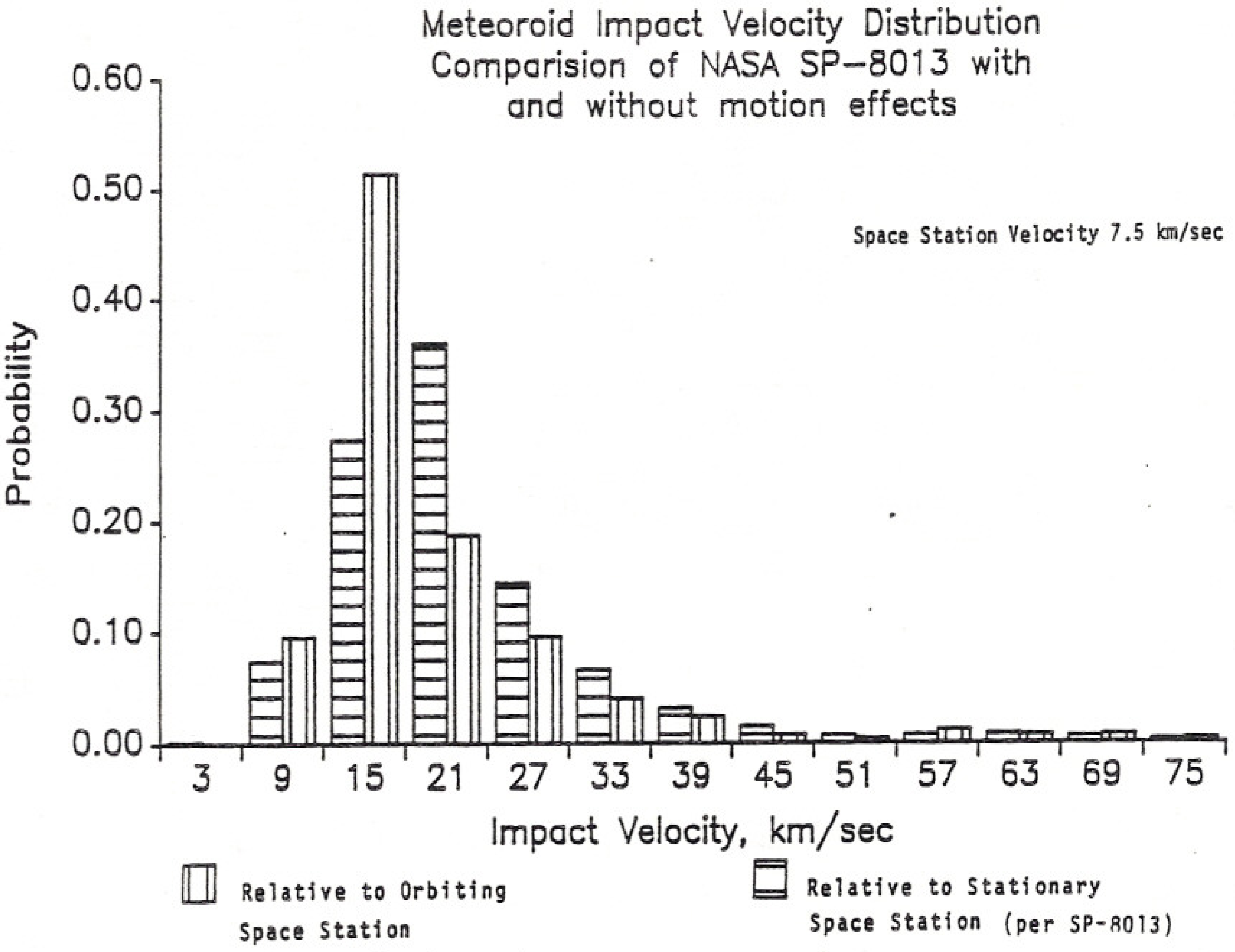


Figure 2.2-3. Meteoroid Impact Velocity Distribution Relative to Space Station

Debris Velocity Distribution

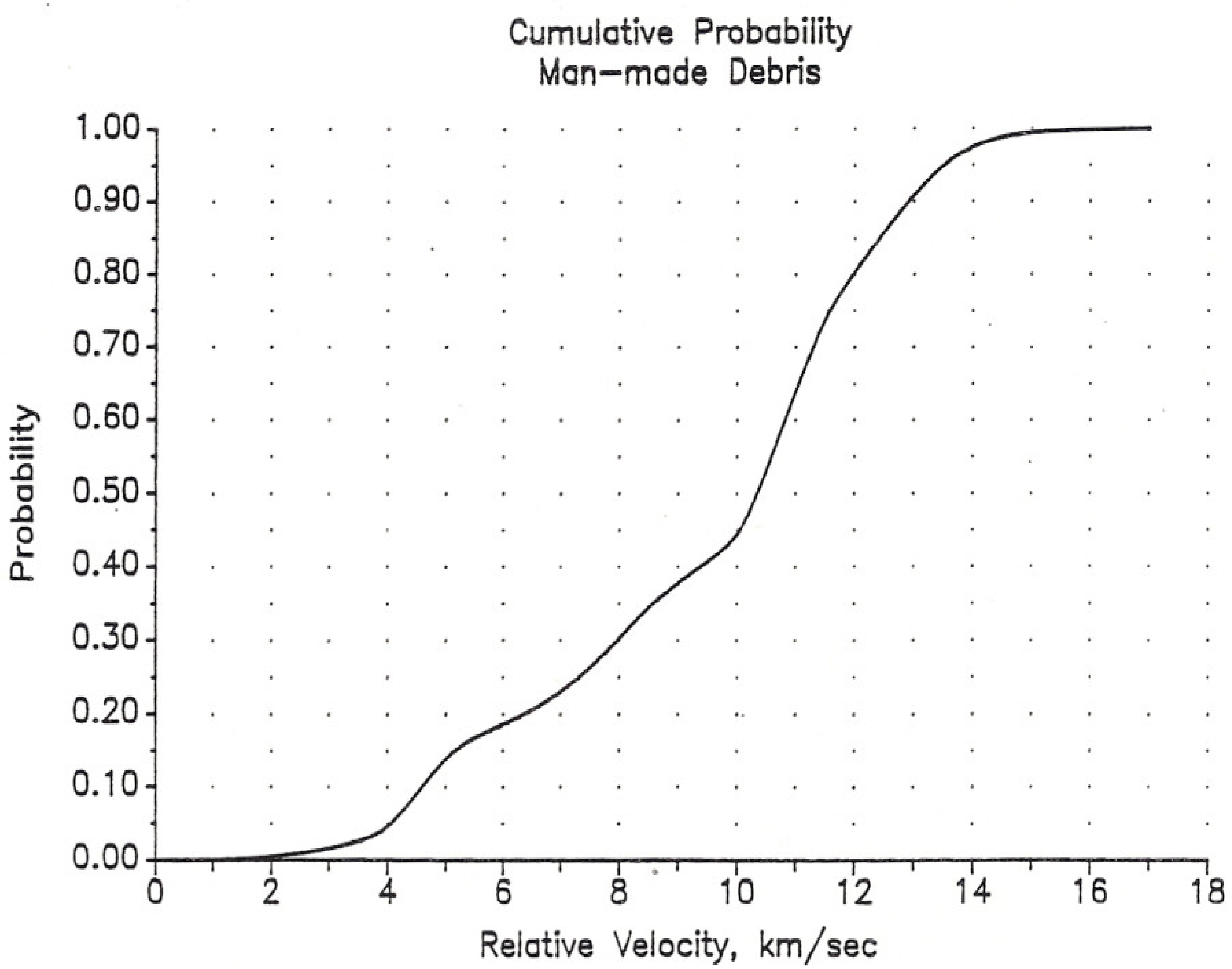


Figure 2.8-2. Impact Velocity Probability Distribution

Wall Filtering Probabilities

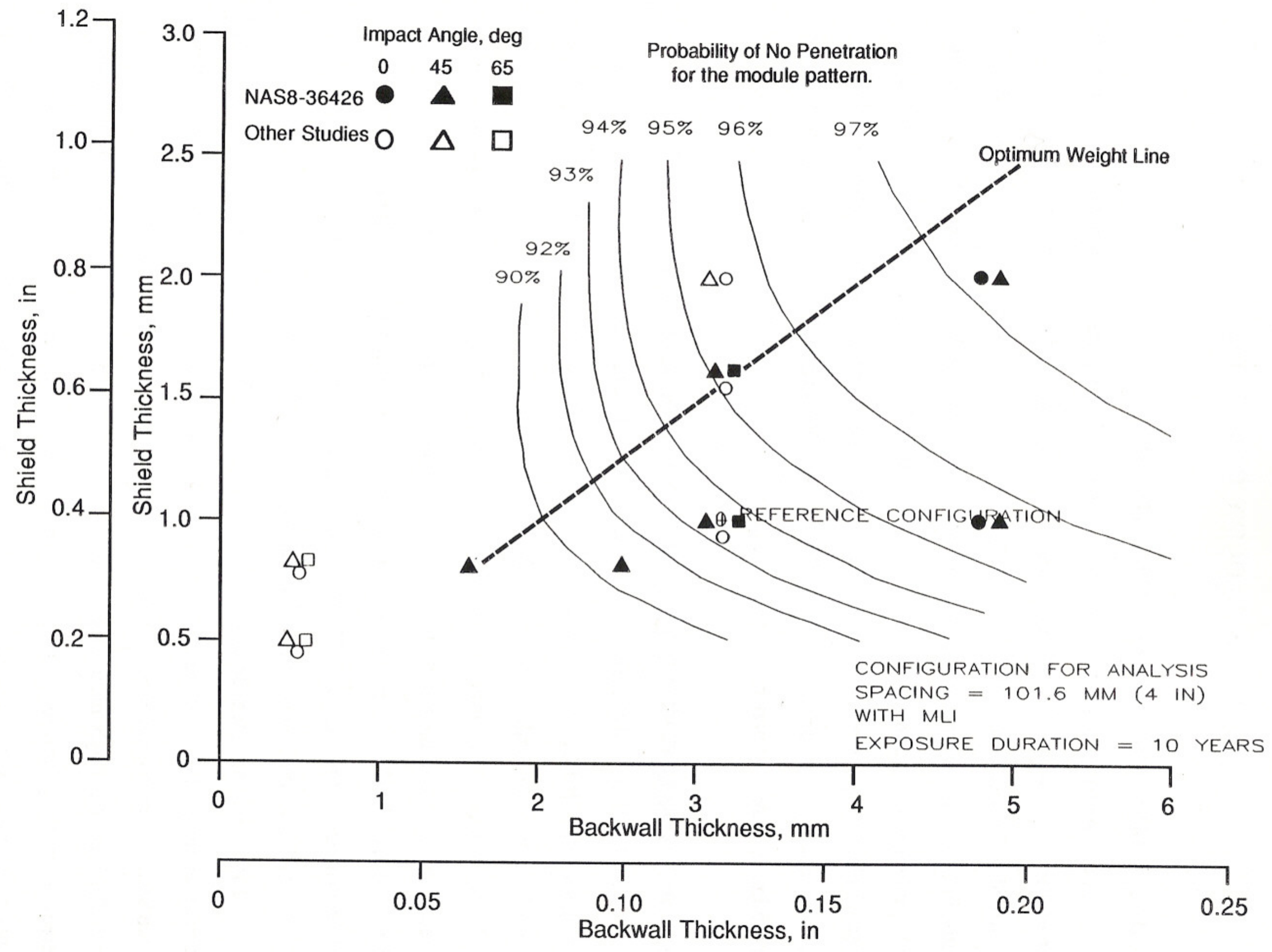


Figure 3.2-1. Module Design Data Comparison With Test Data.

ISS Penetration Risk Map