Not with a Bang

The Sisyphean life outside The Box

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Intro

- Bio
  - Schooled in semiconductor physics and fabrication, Rensselaer Polytech ’73
  - Friend and I started digital clock company then:
    I. Banking systems, French fry ‘computers’, NASA contractor (systems support), NASA employee (Fault Tolerant Systems, Neural Nets, Active Noise Control)

Perspective

- Pursuing creative ‘out of the box’ solutions to problems is a lot like pushing the same boulder up a hill over and over and over again.

Overview

- My career challenges
  - Fault Tolerant Systems Reliability Analysis
  - Characterizing Coherence in the Turbulent Boundary Layer
  - Dream Chaser Transonic Loads
- Current Musings
  - AI – Knowledge Fusion
  - Climate Change – The Core of the Problem
  - Hubble’s Law

Fault Tolerant Digital Systems in Commercial Aircraft (1980)

- Probability of system failure of 10^{-9} at 10 hours.
- Redundancy and failure recovery
- Verification cannot be done via physical system stress testing
- Failure Modes and Effects Analysis (FMEA) and Fault Trees were modeling state of the art. (5-8 processing units)

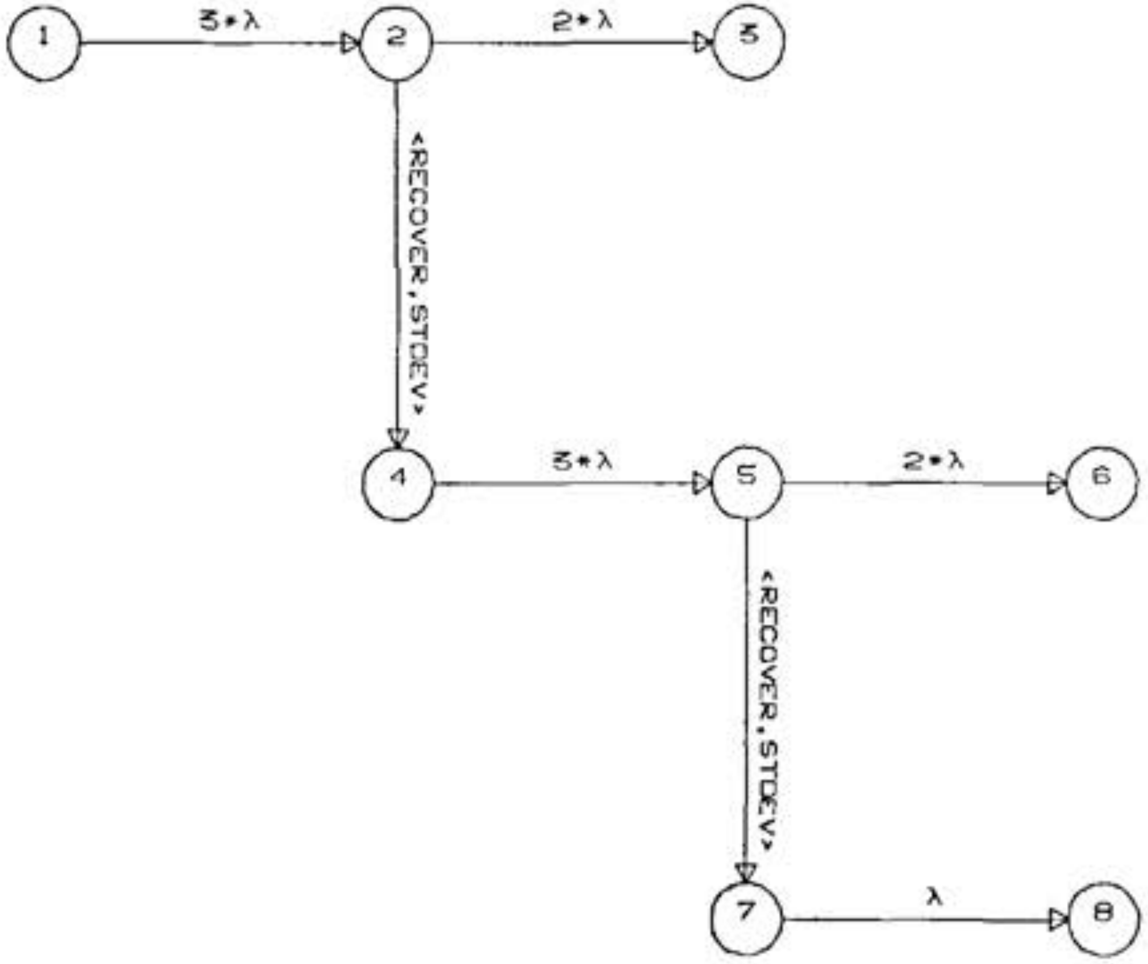
The Evolution of Reconfigurable System Analysis

- Electronics have exponential failure rates (memoryless)
  - Markov modeling
- Recovery algorithms are non exponential > stiff differential equations > computationally expensive
- Introduce mathematical theory of bounded solution* > computable semi-Markov models > SURE

*Allan L. White, “Synthetic Bounds for Semi-Markov Reliability Models”, NASA-CR-178008, 1986

SURE Notation for a triplex, repairable FCS*

1 read triadp1;
2: LAMBDA = 1E-6 TO* 1E-2;
3: RECOVER = 2.7E-4;
4: STDEV = 1.3E-3;
5: 1,2 = 3*LAMBDA;
6: 2,3 2*LAMBDA;
7: 2,4 <RECOVER,STDEV>;
8: 4,5 = 3*LAMBDA;
9: 5,6 2*LAMBDA;
10: 5,7 <RECOVER,STDEV>;
11: 7,8 = LAMBDA;
12: POINTS = 10;
13: TIME = 6;



* Ricky. W. Butler, "The SURE Reliability Analysis Program", NASA TM 87593, 1986

ASSIST Notation*

```
(*  TRIAD WITH COLD SPARES  *)

N_PROCS = 3;            (* Number of active processors *)
N_SPARES = 2;           (* Number of spare processors *)
LAMBDA_P = 1E-4;        (* Failure rate of active processors *)
LAMBDA_S = 1E-5;        (* Failure rate of spare processors *)
DELTA = 3.6E3;          (* Reconfiguration rate *)

SPACE = (NP: 0..N_PROCS,        (* Number of active processors *)
         NFP: 0..N_PROCS,       (* Number of failed active processors *)
         NS: 0..N_SPARES,       (* Number of spare processors *)
         NFS: 0..N_SPARES);     (* Number of failed spare processors *)

START = (N_PROCS, 0, N_SPARES, 0);

DEATHIF 2 * NFP >= NP;

IF NP > NFP TRANTO NFP = NFP+1 BY (NP-NFP)*LAMBDA_P;
   (* Active processor failure *)

IF NS > NFS TRANTO NFS = NFS+1 BY NS*LAMBDA_S;
   (* Spare processor failure *)

IF (NFP > 0 AND NS > 0) THEN
   IF NS > NFS   (* Replace failed processor with working spare *)
      TRANTO (NP, NFP-1, NS-1, NFS)
             BY FAST (1-(NFS/NS))*NFP*DELTA;
   IF NFS > 0    (* Replace failed processor with failed spare *)
      TRANTO (NP, NFP, NS-1, NFS-1)
             BY FAST (NFS/NS)*NFP*DELTA;
ENDIF;
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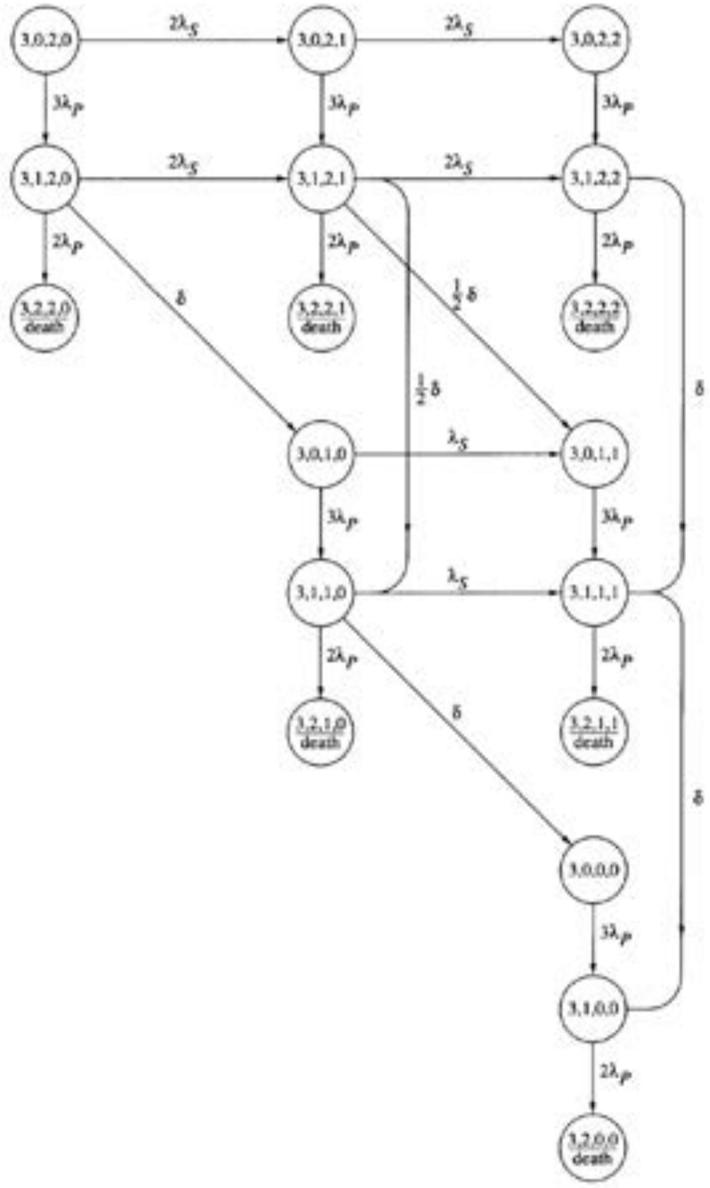
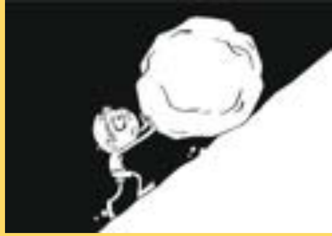


Figure 9. Semi-Markov triad model with cold spares (ASSIST state numbers).

* Sally C. Johnson and David P. Boerschlein, “ASSIST User Manual”, NASA TM 4592, 1995

Who’s your customer?



- In NASA Aero at the time, the measure of a new technology’s value was of the aerospace industry’s adaptation of the technology. Life critical technologies’ adoption rate is slow.
- Boeing system engineers could not make the leap from their system design paradigm of ‘boxes and lines’ to a Markov model.
- Bridging this gap became an onus that was never directly addressed but always there.

AI Approach to Automated Failure Modes and Effects Analysis (FMEA) circa 1990

- Attempted to capture FMEA methods and implement them in a LISP based AI system.
  - Boeing system engineer (FMEA analyst), mathematician and AI expert.
  - Knowledge capture and high-level system design completed.
  - Personnel changes torpedoed project.

Taking reliability modeling to another level

- Large reconfigurable mesh networks were being prosed for digital avionics
  - These networks would have complex redundancy management algorithms
  - Markov model sizes with potentially millions of states possible
  - Computationally difficult at the time (~1990).
- Dr. David Nichols of William and Mary sought to parallelize SURE to analyze these large models. I persuaded him to instead use ASSIST as the modeling language instead. ASSURE was born[1]. (serendipity + compatibility)
- REST[2] embodied a modeling language that elevated abstraction to an object oriented level. This provided the syntax and semantics necessary to conveniently define large reconfigurable networks.

[1] “Parallelized Reliability Estimation of Reconfigurable Computer Networks”, David Nichol, Subhendu Das and Dan Palumbo, NASA CR 182101, 1990.
[2] “Users Guide to the Reliability Estimation System Testbed (REST)”, David M. Nichol, Daniel L. Palumbo and Adam Rifkin, NASA TM 107596, 1992)

REST into BONeS

- At the time, Boeing was developing the Vehicle Management System (VMS) for Northrop's YF-23.
- They were using a network analysis tool (BONeS) to define the VMS system components, interconnections and resulting performance.
- I realized that the BONeS 'boxes and lines' graphical interface could be used as a front end to REST. (again, serendipity)
- Dr. Nichols took on the task to embed REST in BONeS. It worked well.
- Boeing used the tool to do the reliability analysis of the YF-23 VMS system and went on (so I heard) to use it for other projects as well.

Automated Failure Modes and Effects Analysis

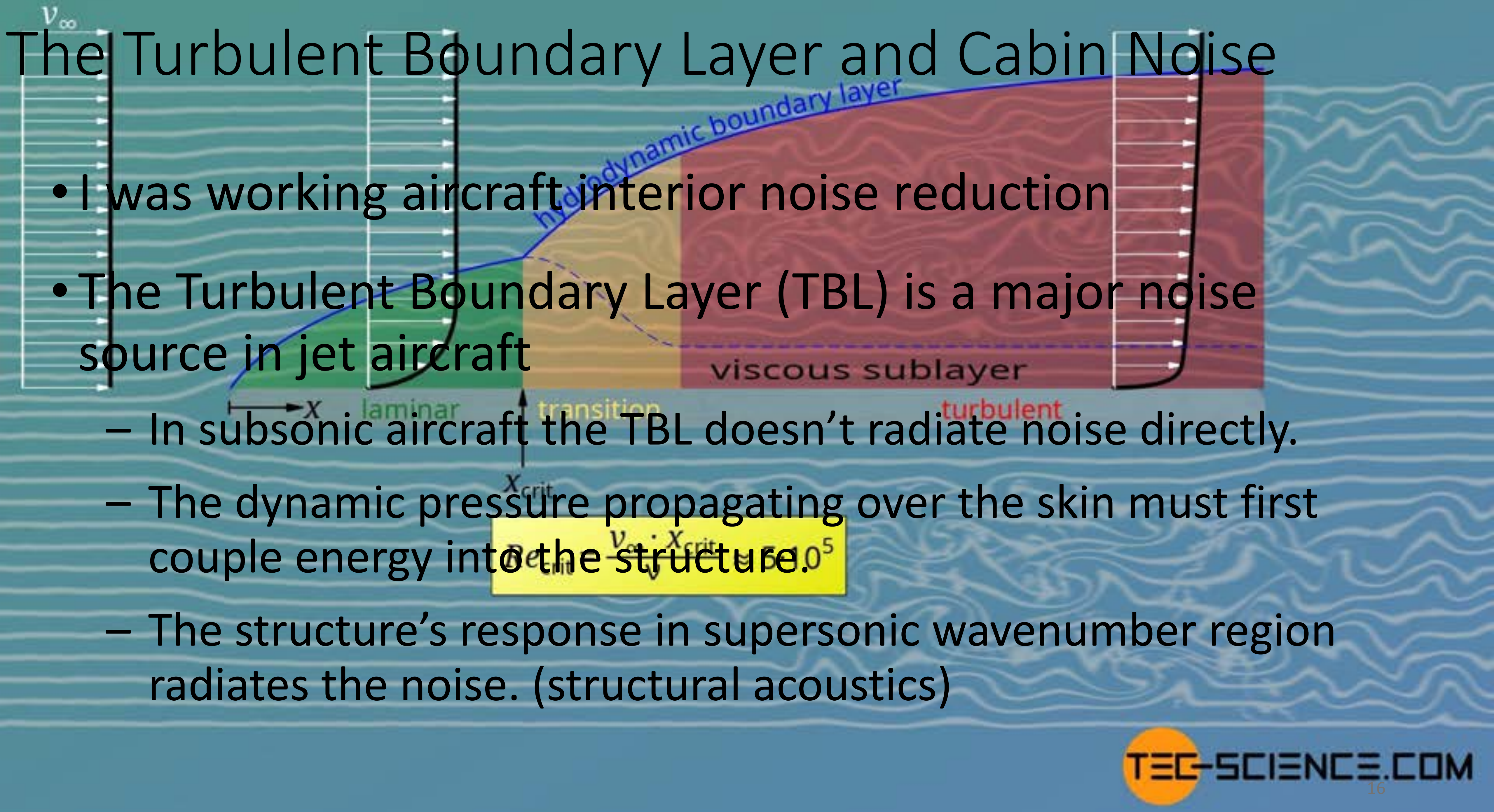
- The expressivity of the REST Modeling Language (RML) and the facility of a graphical interface provided a means by which the system designer could embed definitions of a systems' components' failure modes and effects.
  - The REST/ASSURE subsystem propagated the effects throughout the system, building and solving the Markov model along the way.
- The result was
  (1)The block diagram interface for system designers Boeing had sought, and,
  (2)A compact form of the failure modes and effects of the entire system.
- The system failure behavior embedded in the compact FMEA semantic network is explored 'bottom up' for reliability analysis. This same information could also be interrogated top down to deduce source of failure from error syndrome.

What Happened?

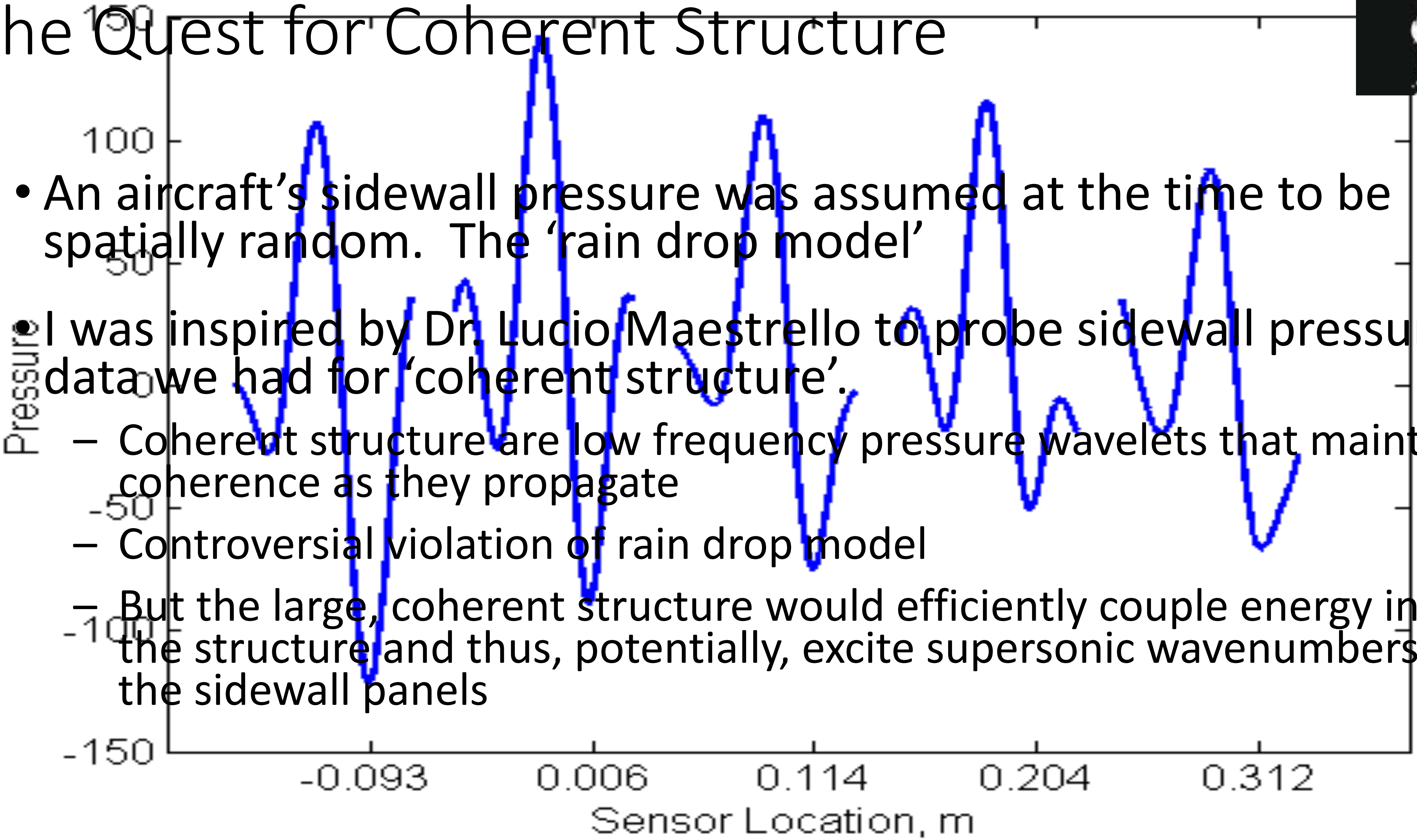
- I contacted a NASA Shuttle program manager who was working a similar area and asked if he was interested in this new tool. He replied that if I sent him $50k he would give me a bullet.
- One of my colleagues persuaded management that what I said I was doing (and actually did) couldn't be done. There was no open review. Just closure.
- I left the organization for Acoustics (Active Noise Control)

The Turbulent Boundary Layer and Cabin Noise

- I was working aircraft interior noise reduction
- The Turbulent Boundary Layer (TBL) is a major noise source in jet aircraft
  - In subsonic aircraft the TBL doesn't radiate noise directly.
  - The dynamic pressure propagating over the skin must first couple energy into the structure.
  - The structure's response in supersonic wavenumber region radiates the noise. (structural acoustics)



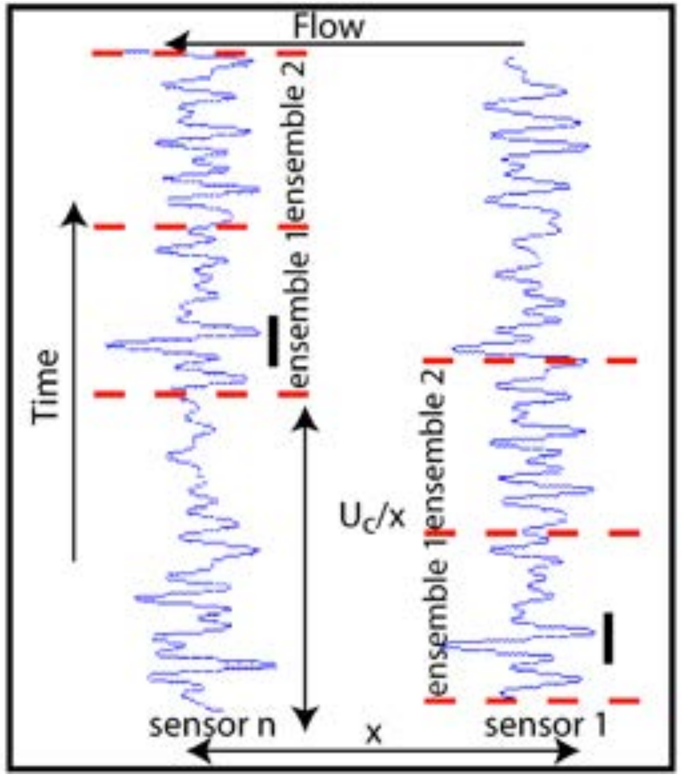
The Quest for Coherent Structure



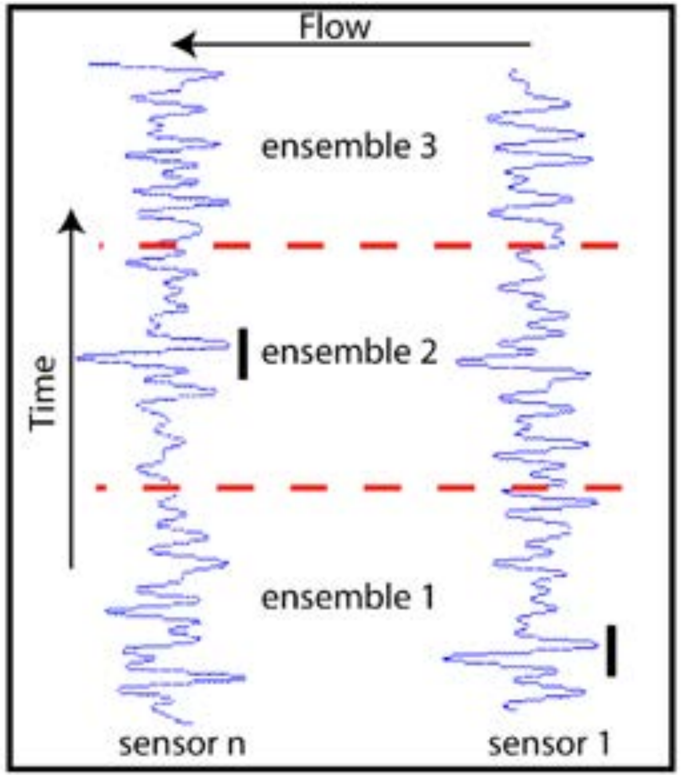
- An aircraft's sidewall pressure was assumed at the time to be spatially random. The 'rain drop model'
- I was inspired by Dr. Lucio Maestrello to probe sidewall pressure data we had for 'coherent structure'.
  - Coherent structure are low frequency pressure wavelets that maintain coherence as they propagate
  - Controversial violation of rain drop model
  - But the large, coherent structure would efficiently couple energy into the structure and thus, potentially, excite supersonic wavenumbers in the sidewall panels

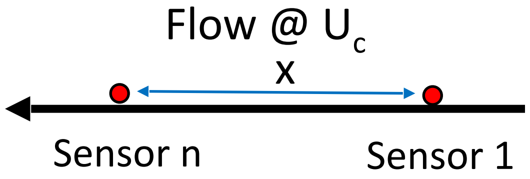
Convection in propagating medium

Offset Sampling



Simultaneous Sampling





Simultaneous sampling of sensors doesn't account for offset in data caused by propagation of flow.

D. Palumbo, Determining correlation and coherence lengths in turbulent boundary layer flight data, Journal of Sound and Vibration (2012), http://dx.doi.org/10.1016/j.jsv.2012.03.015

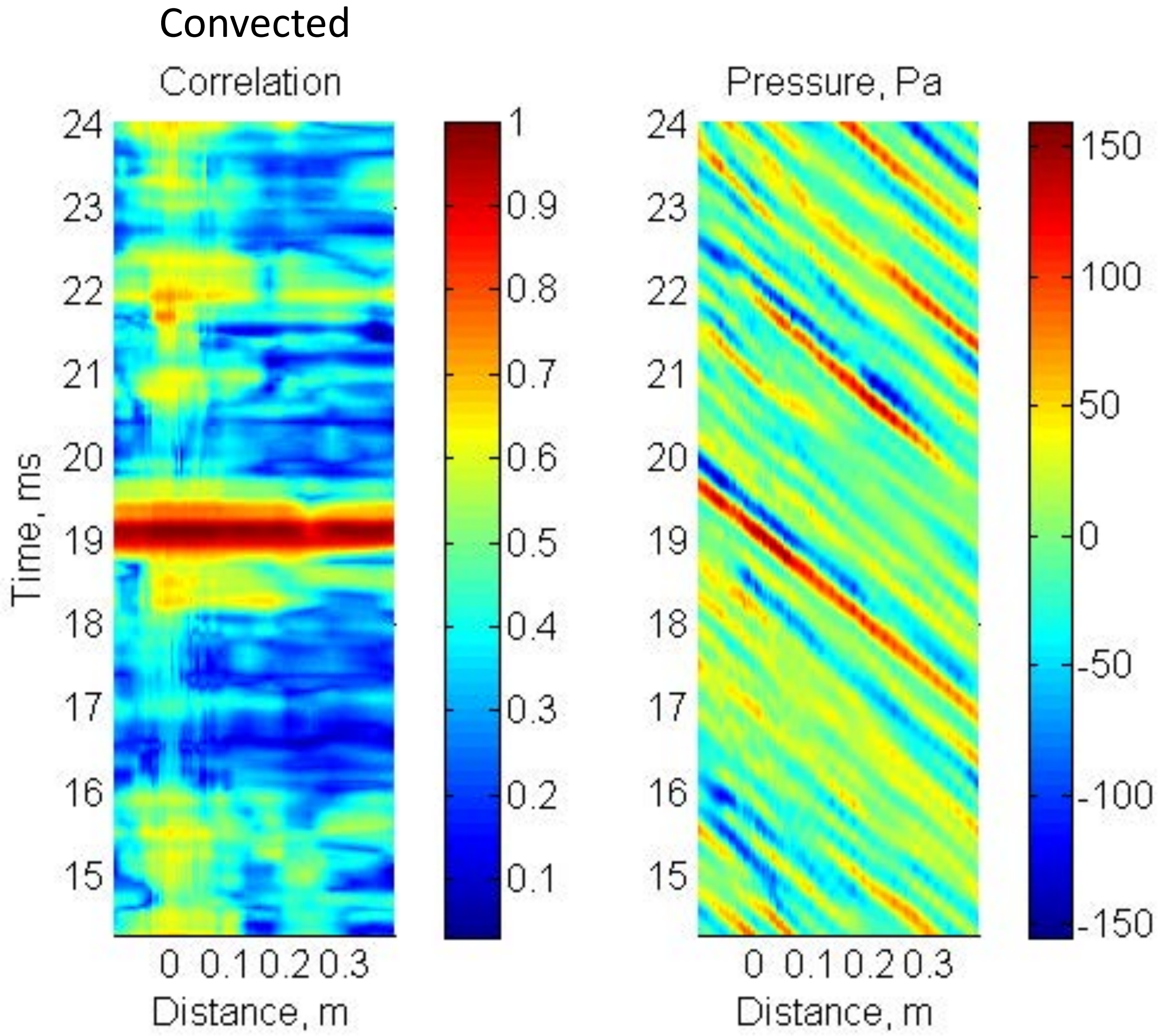
The Convected Cross Correlation and Spectrum

$$\chi(x_0, x_1, t_0, \tau, U_c) = \left\langle p\left(x_0, t_0\right) p\left(x_1, t_0 + \tau + \frac{x_1 - x_0}{U_c} \right) \right\rangle$$

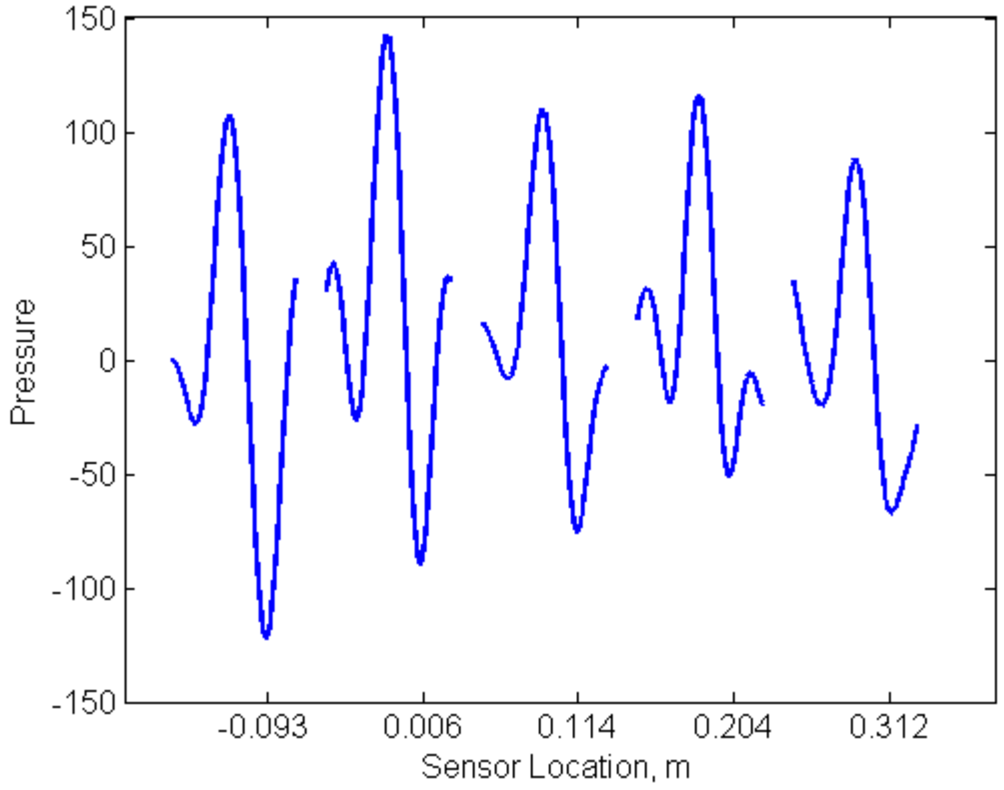
$$\phi\left(x_{0,} x_1, t_0, U_c, f\right) = \int_N \chi(x_0, x_1, t_0, \tau, U_c) e^{-i2\pi f \tau} d\tau$$

- Where χ is the convected cross correlation and ϕ the convected cross spectrum, and x_0 and $x_1$the position of 2 sensors, $t_0$the time of sample at x_0, τ the correlation delay, U_c the convection velocity and *f* the frequency

Detecting and tracking coherent structure

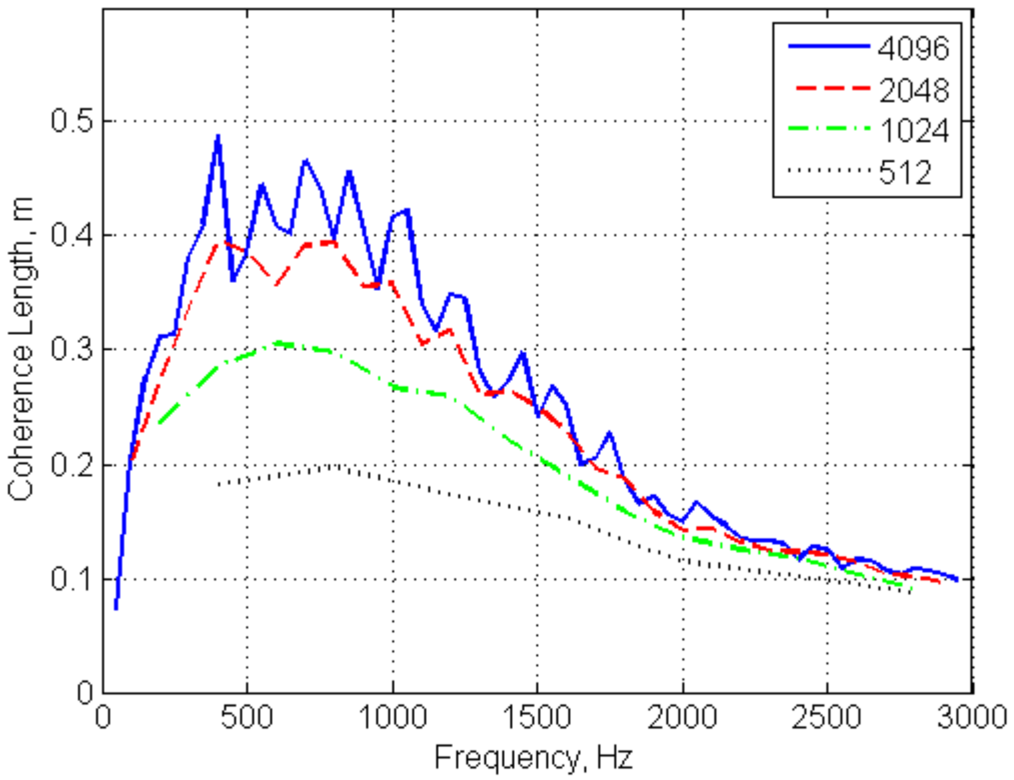


Pressure waveforms from 5 sensors

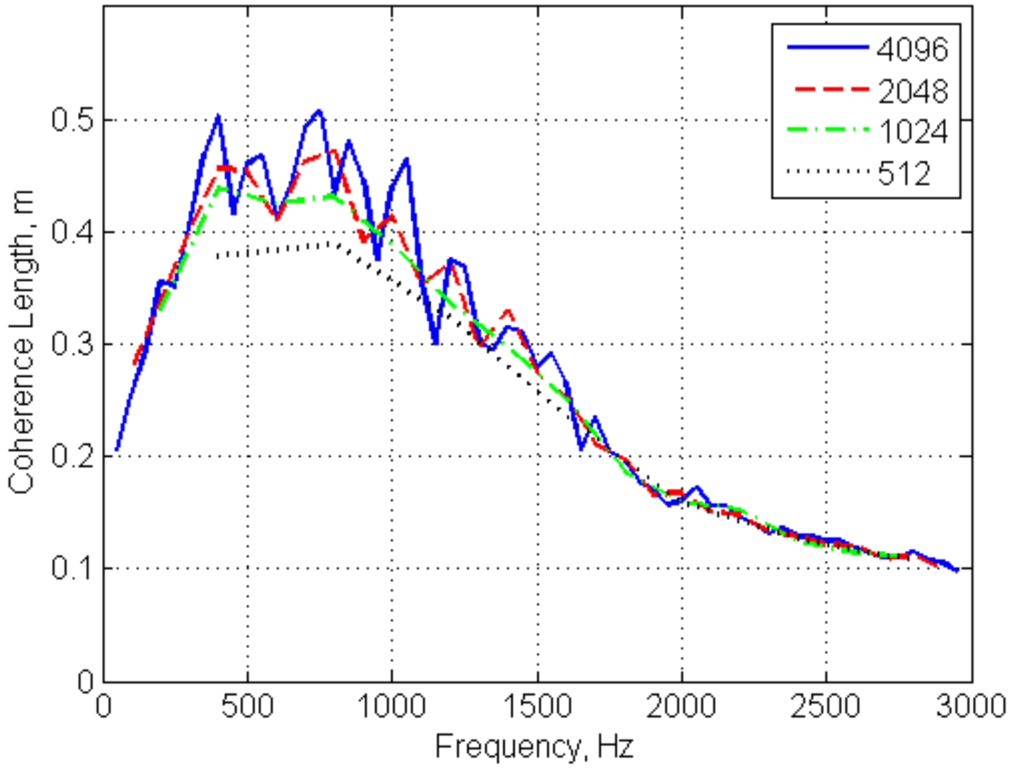


Coherence as a function of sample size

Standard Cross Spectrum



Convected Cross Spectrum



- Using the standard cross spectrum, coherence is dependent on sample size. Larger sample sizes encompass the coherent structure
- The convected cross spectrum collapses the curves to a large degree. Remaining drop in coherence may be due to increase in bin width from 50 to 400 Hz implying the coherent structures have a bin width of 50 to 200 Hz.

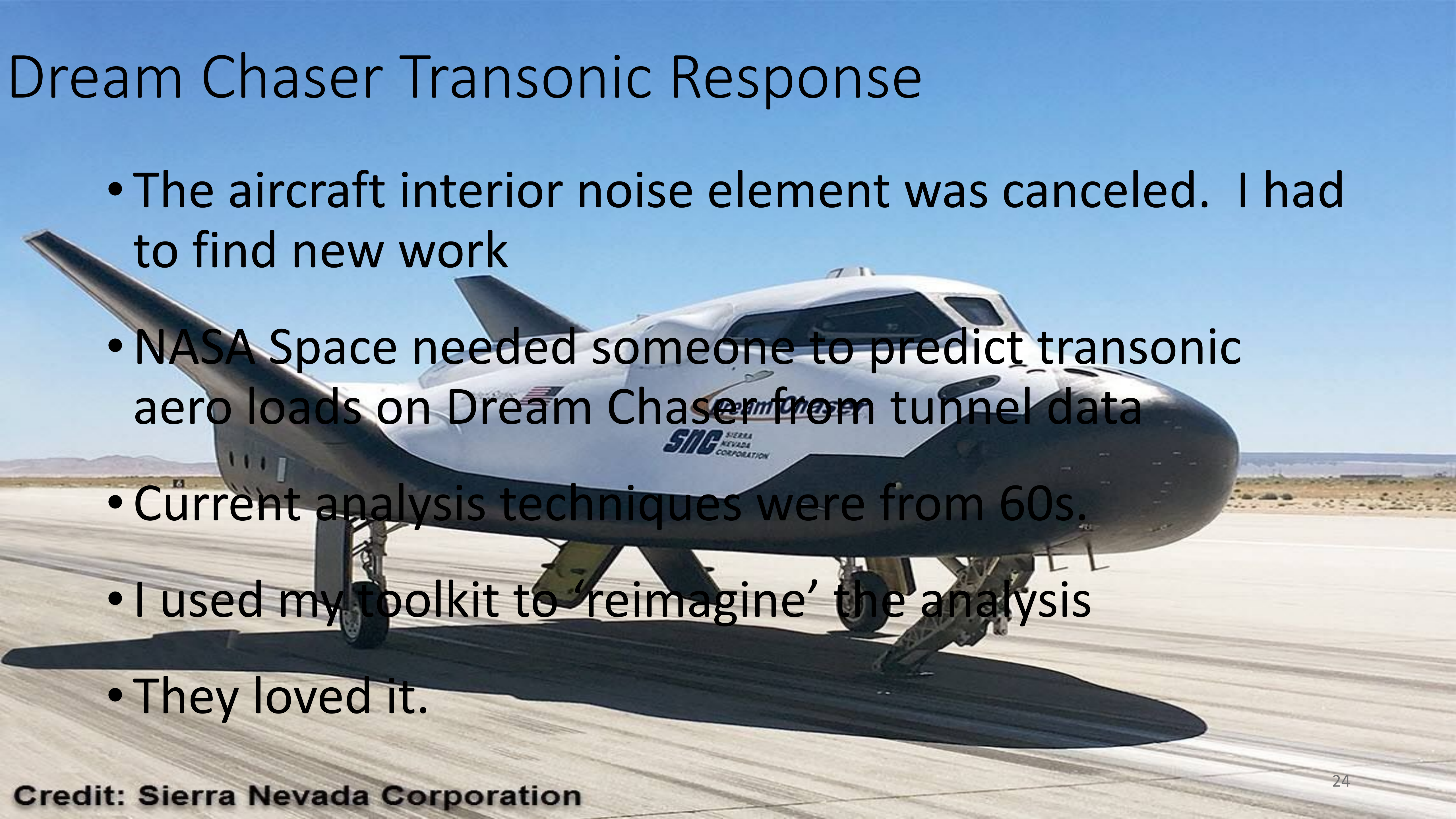
What Happened?

- The AIAA rejected my paper not for technical reasons, but because, in their opinion, if the convected cross spectrum was, indeed, necessary, **it would invalidate 50 years of research**.
- The Journal of Sound and Vibration published the paper because (I paraphrase) they couldn't find anything wrong with it. (Bendat and Piersol, "Random Data")
- A second paper* develops a two-process coherence model which separates the gaussian, outer layer, coherent structure from the exponential inner layer. Efimtsov's exponential predictions verified.

*D. Palumbo. The variance of convection velocity in the turbulent boundary layer and its effect on coherence length, Journal of Sound and Vibration (2013), http://dx.doi.org/10.1016/j.jsv.2013.02.010i

Dream Chaser Transonic Response

- The aircraft interior noise element was canceled. I had to find new work
- NASA Space needed someone to predict transonic aero loads on Dream Chaser from tunnel data
- Current analysis techniques were from 60s.
- I used my toolkit to ‘reimagine’ the analysis
- They loved it.



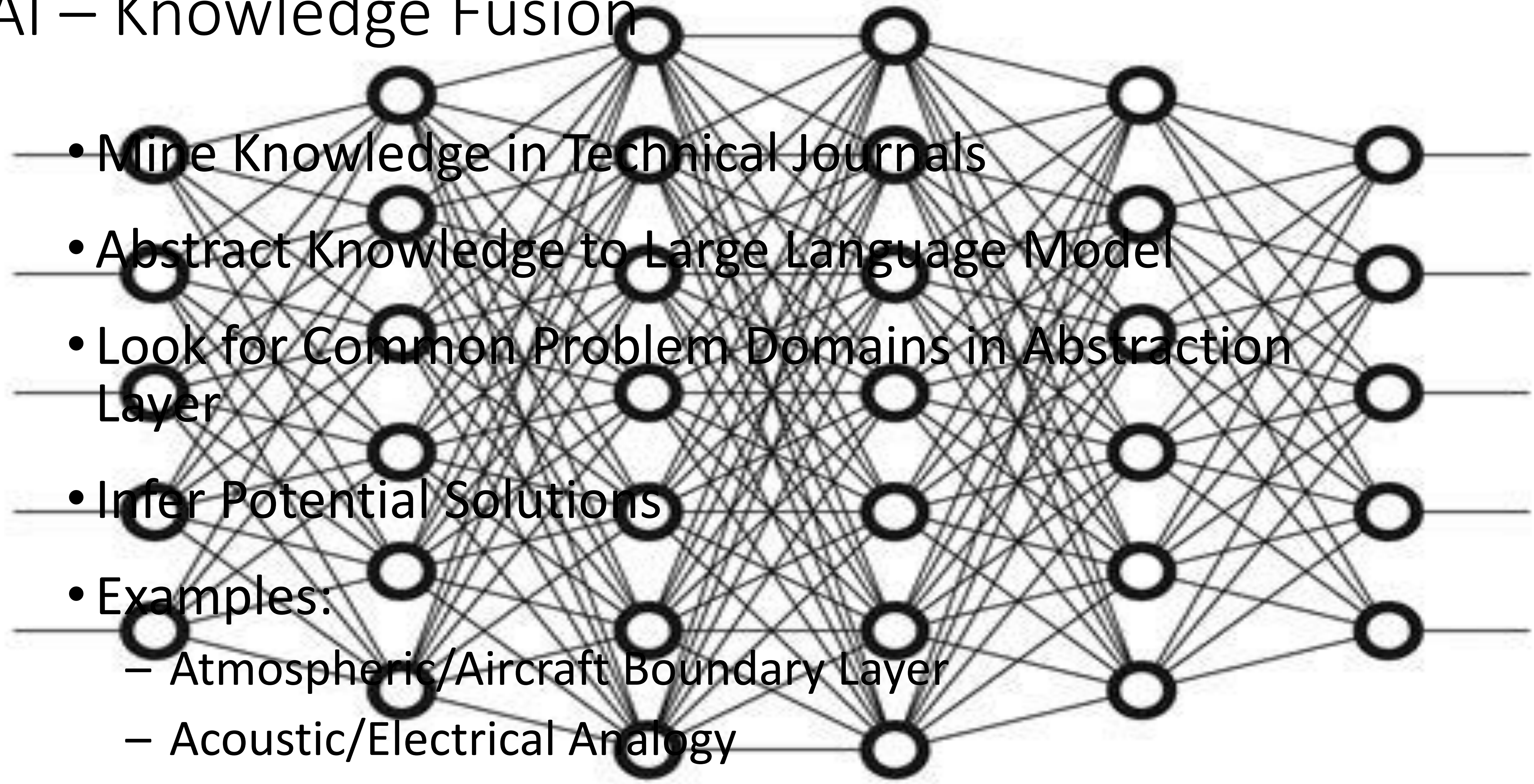
Credit: Sierra Nevada Corporation

What’s the Lesson?

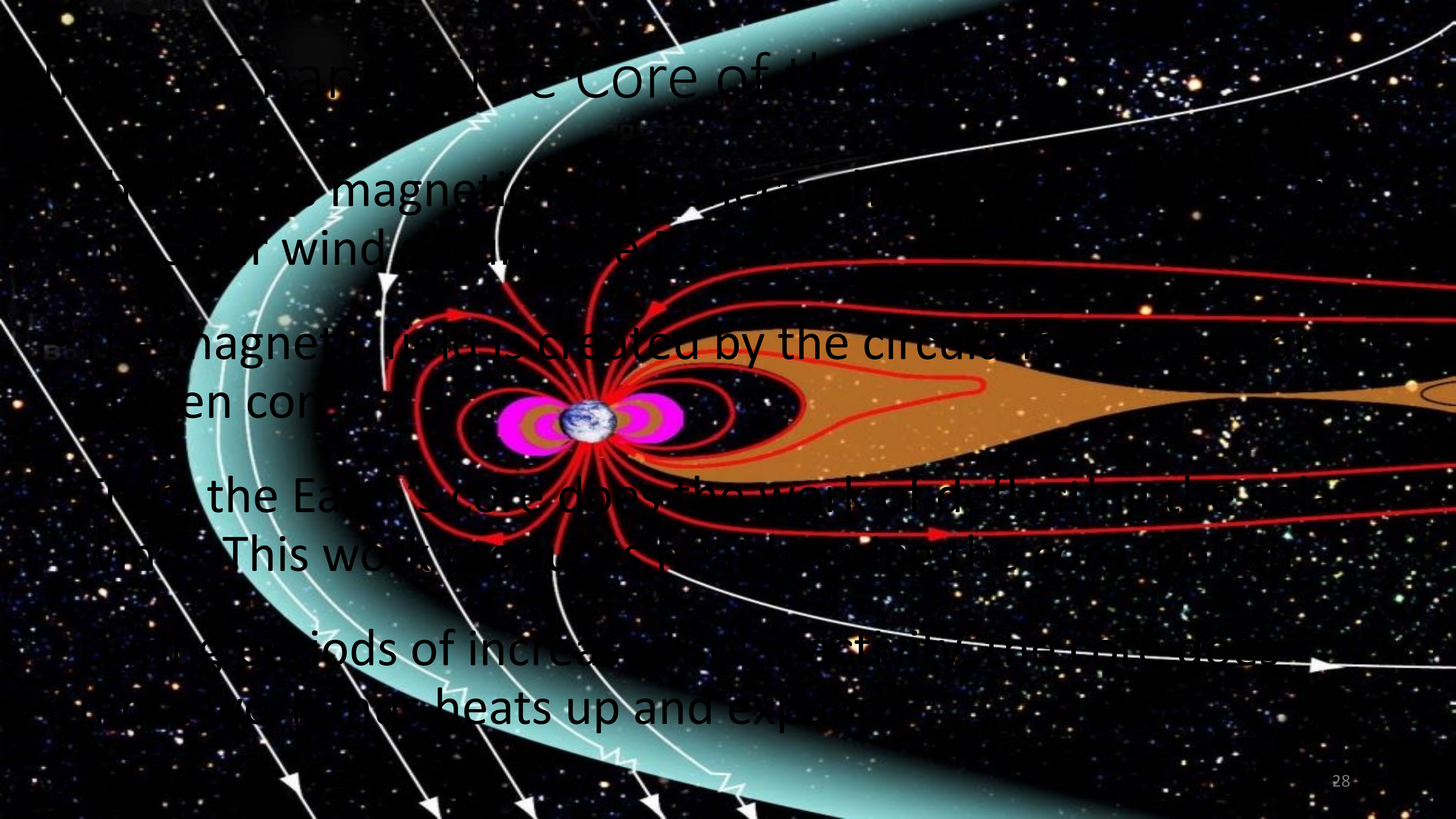
- My research results were of little value to NASA Aero.
  - We needed ‘customer’ buy-in
- Your line management must be fully vested in the area you’re working.
- NASA Space, however, saw value
  - Exploding rockets are embarrassing

Current Musings

AI – Knowledge Fusion



- Mine Knowledge in Technical Journals
- Abstract Knowledge to Large Language Model
- Look for Common Problem Domains in Abstraction Layer
- Infer Potential Solutions
- Examples:
  - Atmospheric/Aircraft Boundary Layer
  - Acoustic/Electrical Analogy



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Hubble's Law and the Big Bang

- Hubble observed a red shift in the hydrogen spectrum acquired from every galaxy's radiation he observed.
- He assumed that the red shift was caused by the galaxies' velocity as they moved away from us. Thus, the Universe was expanding.
- He reasoned further that, IN THE BEGINNING, the Universe must have started with all the mass concentrated in one spot and exploded.
  - **Ba Da Boom**.

Not with a Bang

- There exists a phenomena called *gravitational red shift*
  - Electromagnetic spectra are shifted towards lower frequencies as radiation propagates out of a gravity well
- If true, the hydrogen spectrum from our Milky Way's center should be red shifted.
- Unless these gravitational effects are compensated, hydrogen spectrum measurements of a galaxy's light will be biased.
- In our case, on Earth observing other galaxies, the bias will mostly be red.

In Conclusion

- For in the sciences the authority of thousands of opinions is not worth as much as one tiny spark of reason in an individual man. Besides, the modern observations deprive all former writers of any authority, since if they had seen what we see, they would have judged as we judge.”

— Galileo Galilei , Frammenti e lettere