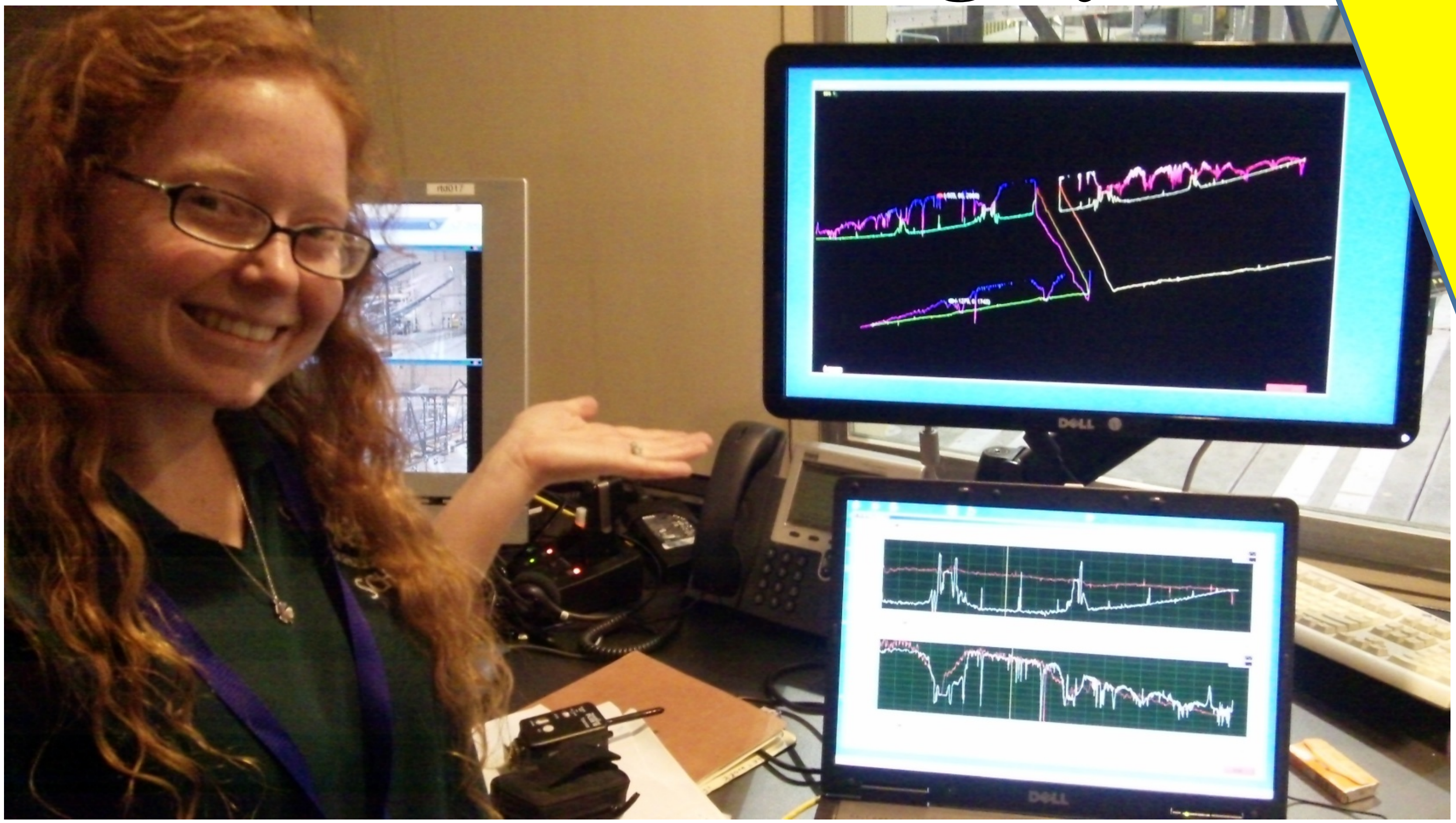
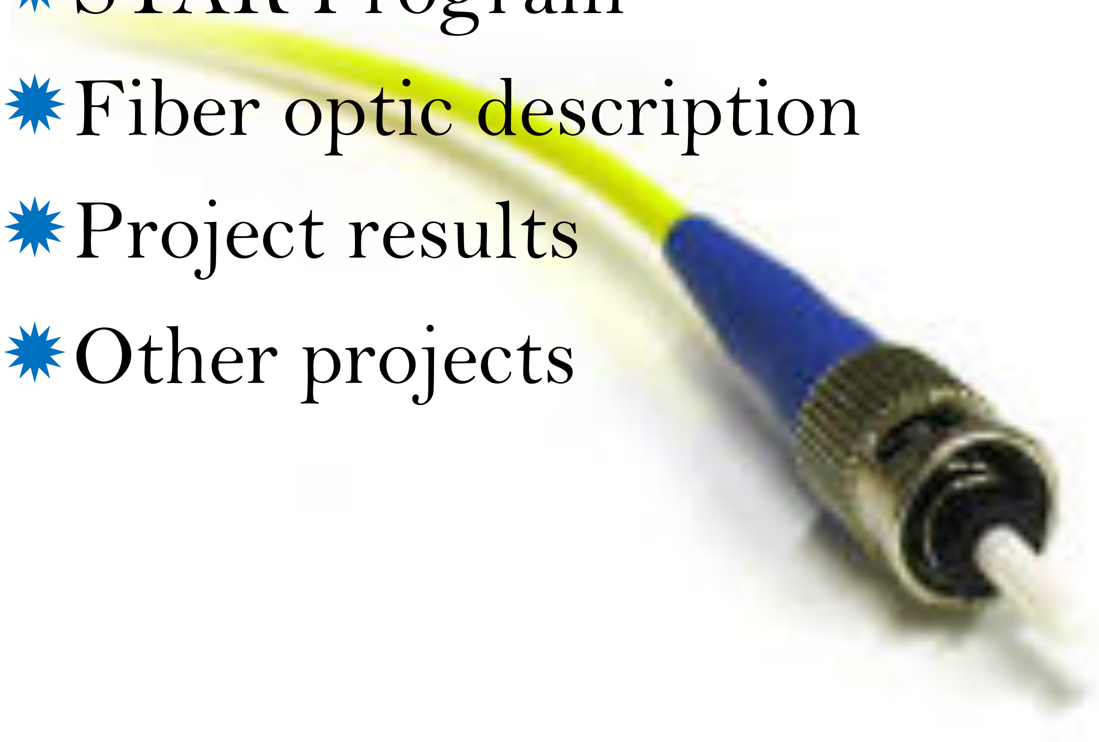
Analyzing Fourier Transforms for NASA DFRC's Fiber Optic Strain Sensing System



Kaitlyn Leann Fiechtner

Outline

- STAR Program
- Fiber optic description
- Project results
- Other projects

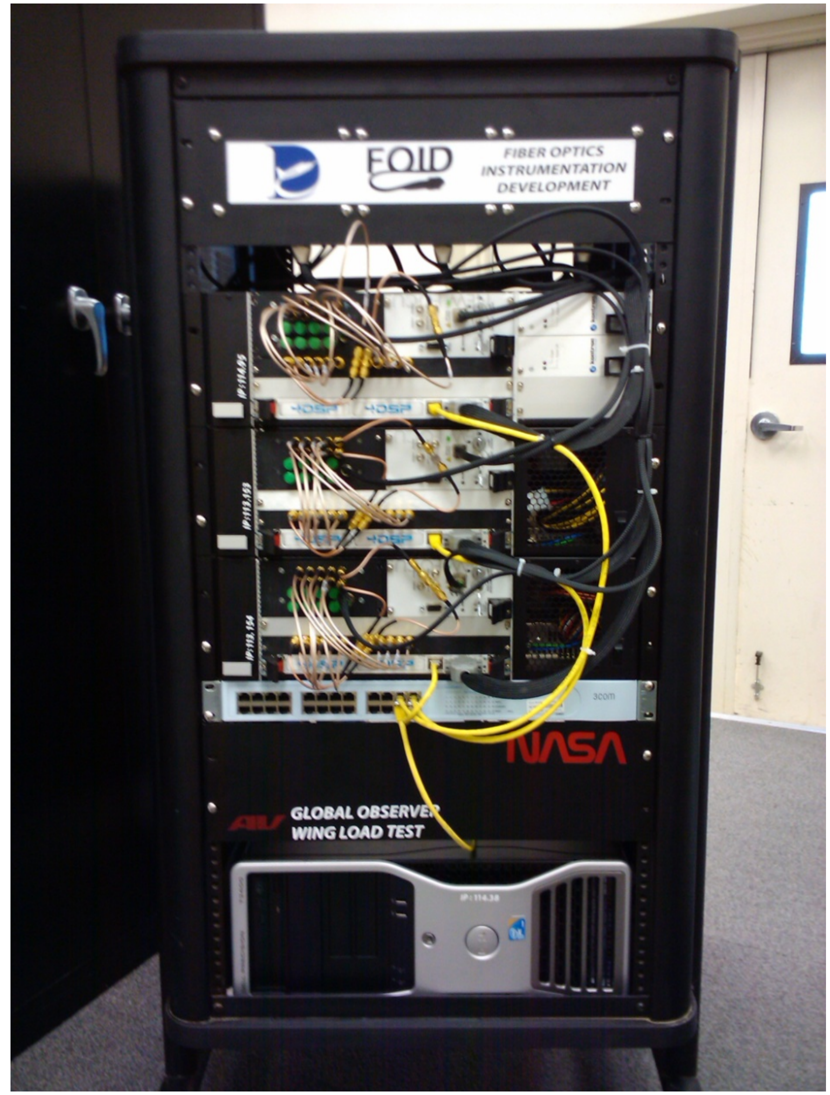


I'm here because…

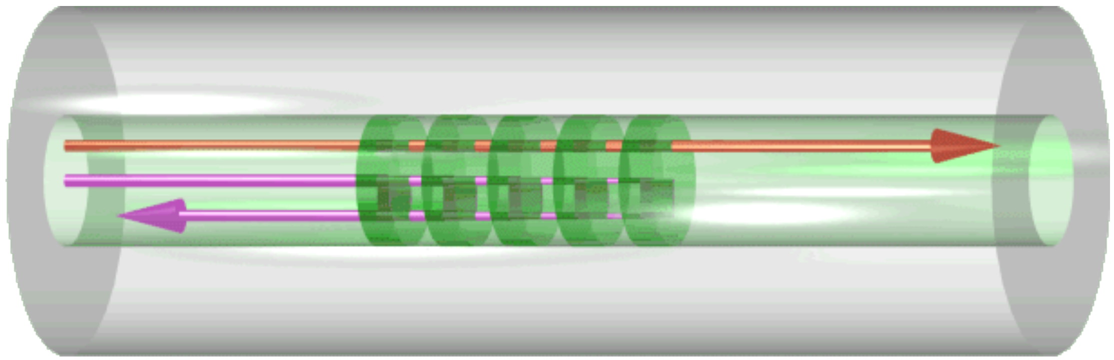
- STAR program (Student Teacher And Researcher)
  - NSF, new program
- Goal:
  - to observe engineers at work
  - to become an honorary engineer
  - all meant to help me encourage future students to work in STEM fields
- Project Aim:
  - understand how the (FOSS) technology works
  - Research and report on the mathematical algorithms involved in the signal processing of the FOSS system

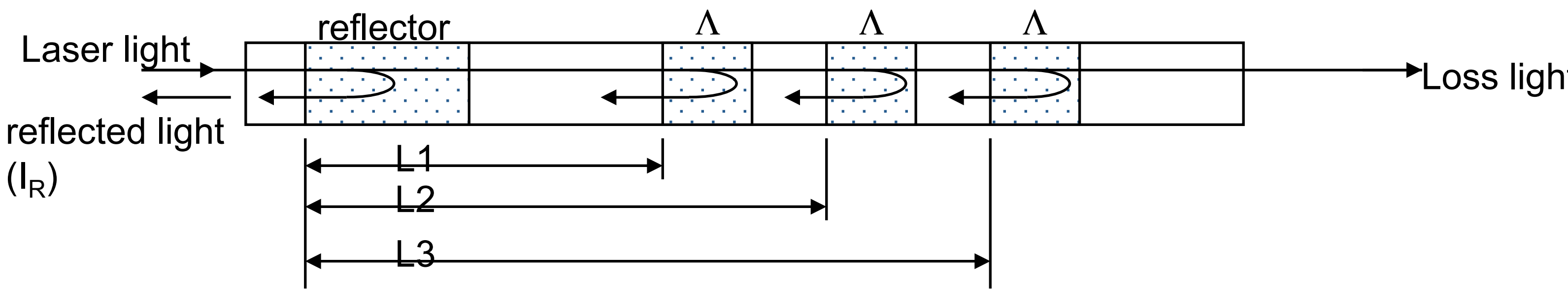
Fiber Optic Strain Sensing Technology

- Items needed:
  - Narrowband wavelength tunable laser
  - Optical fiber(s), filled with FBGs
    - All gratings are written to the same wavelength.
  - Broadband reflector and fiber network
  - Computer(s)
  - Program (LabVIEW) to do mathematical calculations
  - Object for fiber to attach to



How the fibers work





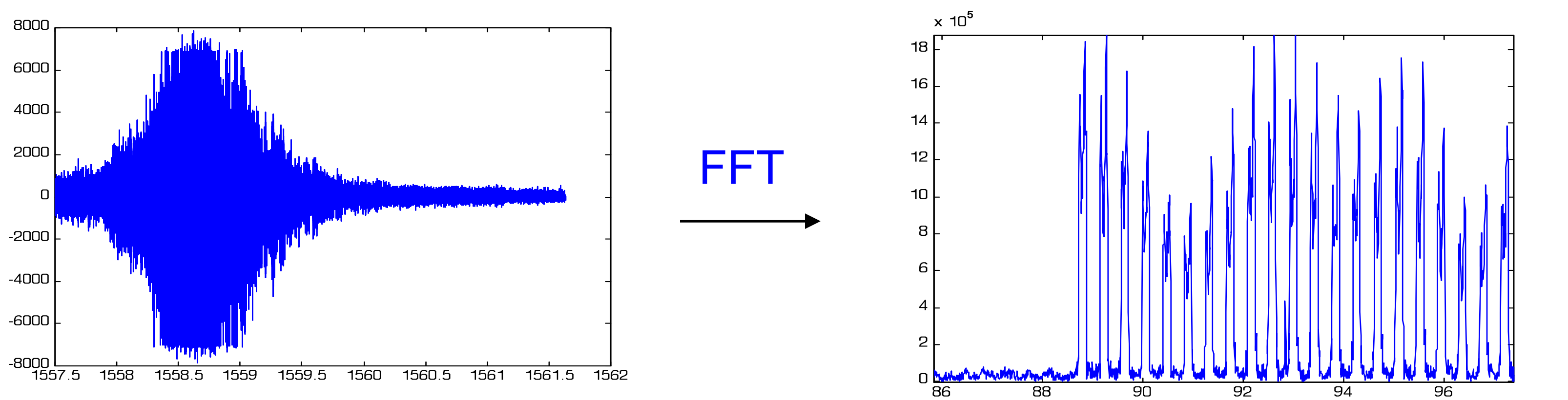
$$I_R = \sum_i R_i Cos(k2nL_i)$$

$$k = \frac{2\pi}{\lambda}$$

R_i – spectrum of i^{th} grating
n – effective index
L – path difference
k - wavenumber

How the math works

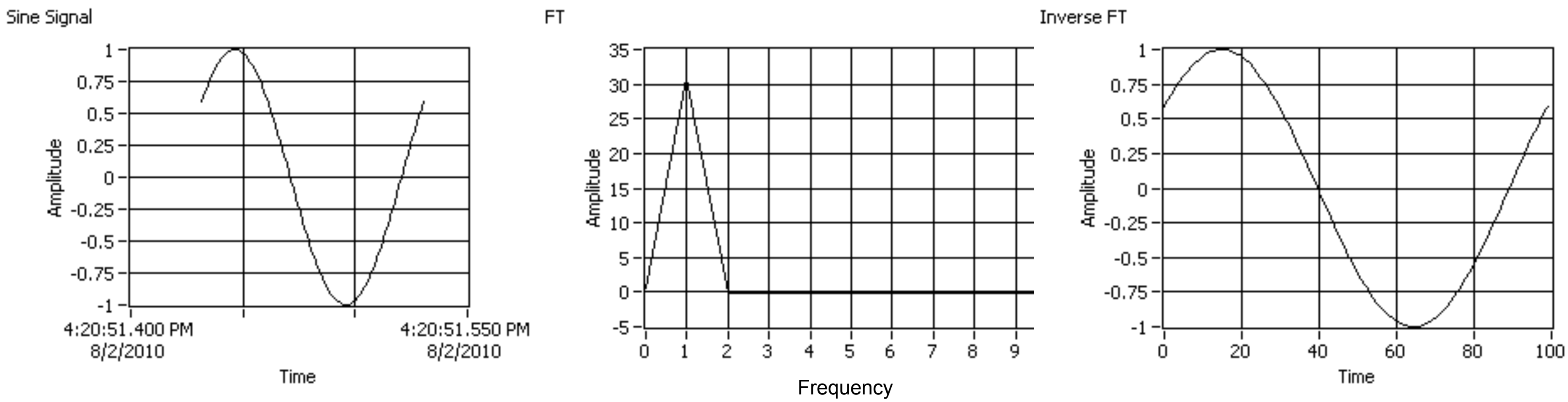
- The Fourier transform separates the I_R waveform $\left(I_R = \sum_i R_i Cos(k2nL_i)\right)$ into sinusoids of different frequency, creating the length domain graph that shows the location of all the FBGs.



Wavelength(λ) domain

Length(L) domain

How Strain is Calculated



- Once the location of the FBGs are identified, the traditional method calls for an inverse Fourier transform
  - Back to original signal
  - Compare wavelength for each grating
  - Strain calculation:

$$\frac{\Delta\lambda}{\lambda} = K\varepsilon$$

K – proportionality constant (0.7-0.8)

How Strain is Calculated

- Once we know were each FBG is located, we can calculate strain
  - Strain is proportional to change in wavelength
  - Strain calculation: $$\frac{\Delta\lambda}{\lambda} = K\varepsilon$$

K – proportionality constant (0.7-0.8)

Research

- Dryden has devised a better way to calculate
  - Only an Fourier Transform, no inverse
  - trace how the wavelength changes from its original wavelength
  - As it's being calculated, it's being graphed in real time, so we can view where strain is instantly
- Need to try finding/creating more efficient transforms
- Basics
  - DFT- Discrete Fourier Transform
  - transform for digital spectral analysis
  - Need wavelength, frequency, and amplitude
  - Usually computed using FFT (Fast Fourier Transform)
- Focus
  - Sliding DFT
  - Goertzel
  - Sliding Goertzel

Sliding DFT

- Computation: faster than DFT, FFT, and Goertzel
  - Windowing function
  - 1 subtraction, 1 addition, and 1 multiplication with each shift
    - very simple comparatively
- Can't use yet
  - according to a study in 2009 by Elisa Russo from Universitia degli Studi di Milano, Italy
  - "Sliding DFT (SDFT) is an analysis technique that thanks to the continuous growth in computer power can become an effective alternative to traditional FFT for DFT calculus…[and because] the CPU power [is] constantly increasing, maybe in a future not so far away, the time of SDFT calculus will be acceptable even in real time applications."

Goertzel

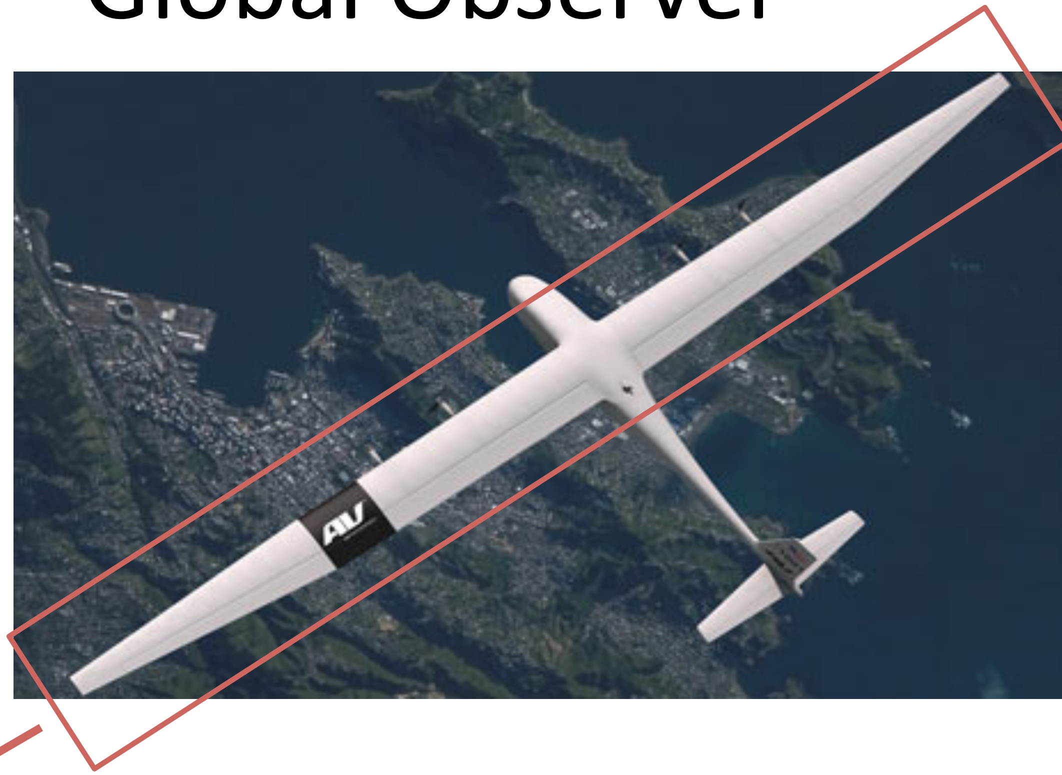
- Uses less CPU horsepower than the FFT (Kevin Banks Embedded.com)
- Computation: faster than DFT and FFT
  - Up to four times faster the data are real-valued
- Impractical for us
  - Goertzel's …algorithms are efficient for a few DFT frequency samples; if more than logN frequencies are needed, O (NlogN) FFT algorithms that compute all frequencies simultaneously will be more efficient Goertzel's Algorithm, Douglas L. Jones, Prof U of Illinois
  - Impractical for FOSS

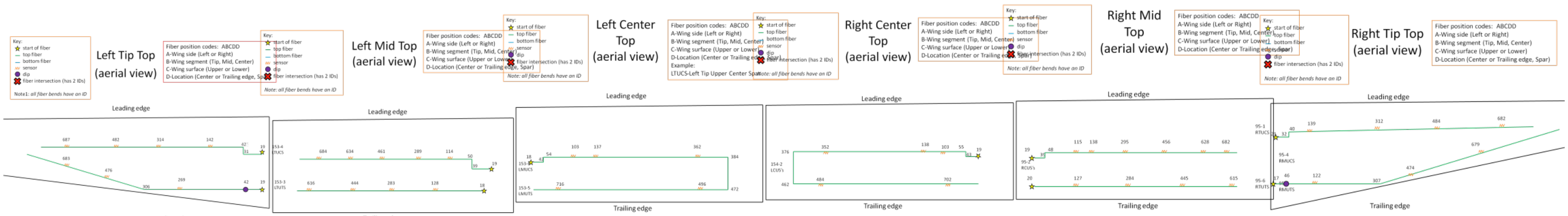
Sliding Goertzel

- Computation: faster than Goertzel, especially in time-varying signals
  - Can compute data before a period is complete
- "Capable of tracking rapid changes in the signal parameters (phase and amplitude)"
  - Calculates p&a for every sample
- Remains accurate even through high noise
- Needs more investigation

Other Projects

Global Observer





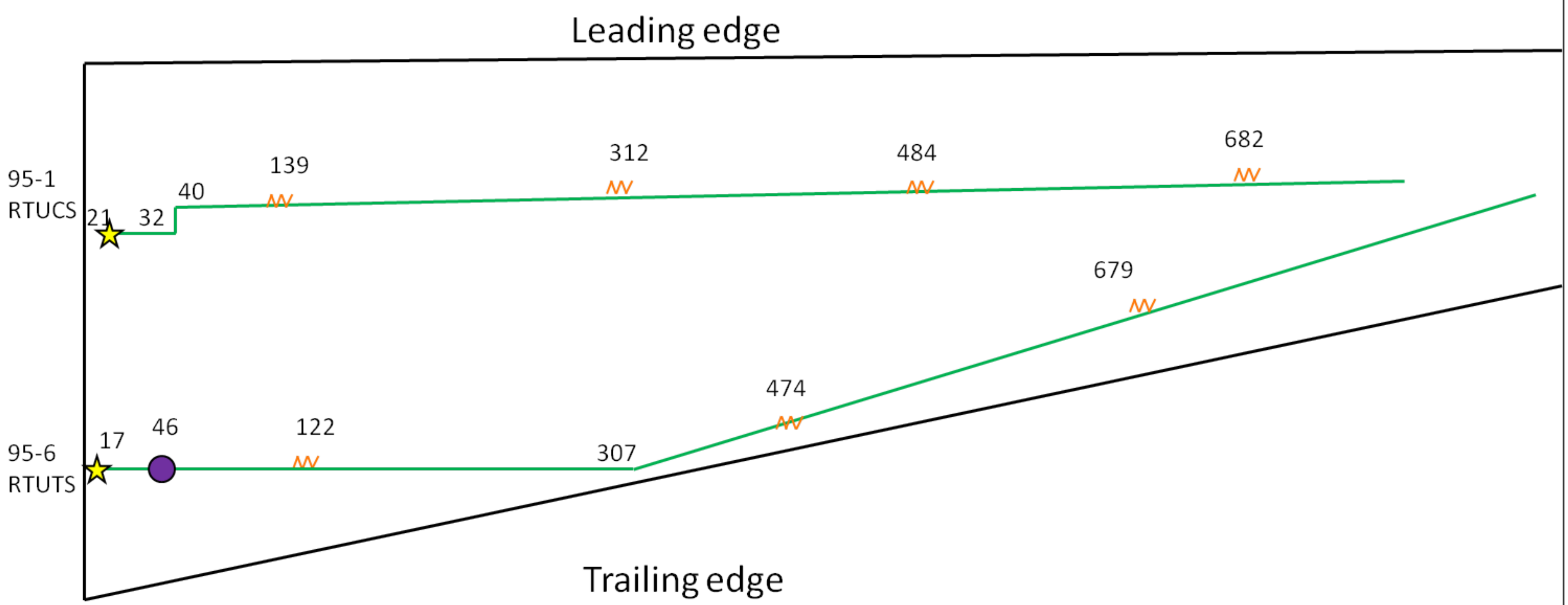
Other Projects

Key:
- start of fiber
- top fiber
- bottom fiber
- sensor
- dip
- fiber intersection (has 2 IDs)

Note: all fiber bends have an ID

Right Tip Top (aerial view)

Fiber position codes: ABCDD
A-Wing side (Left or Right)
B-Wing segment (Tip, Mid, Center)
C-Wing surface (Upper or Lower)
D-Location (Center or Trailing edge, Spar)



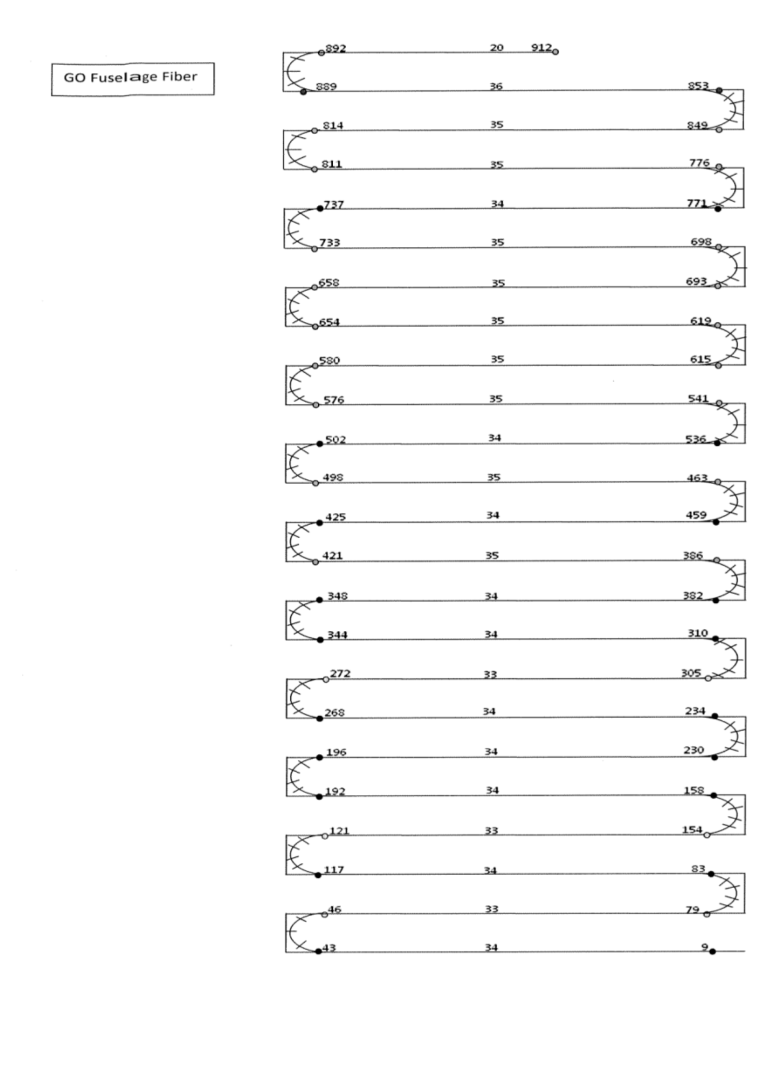
Other Projects Cont.

- The FOSS (fiber optic strain sensing) system is comprised of three computer systems that acquire sensing data from fibers on the test subject. Each computer is connected to 8 channels and each channel consists of one fiber. Since there are 18 fibers on Global Observer's wings, one computer has only 2 channels corresponding to the wing fibers.
- The computer systems are identified by their IP addresses. IP address 114.95 refers to the computer that obtains data from the right wing fibers. IP address 113.154 refers to the computer that obtains data from the left center fibers on the wing (this is the 2 channel computer). 113.153 refers to the address of the computer that obtains data from the rest of the 8 fibers on the left wing. You can locate a fiber on the wing by finding the computer's IP address and the channel that corresponds to the fiber; this information can be found in the table below.
- Note: The starting point for sensing is different on each fiber. The last column in the table below indicates the start of each fiber's Bragg strain sensor.

Location of fibers on Wing

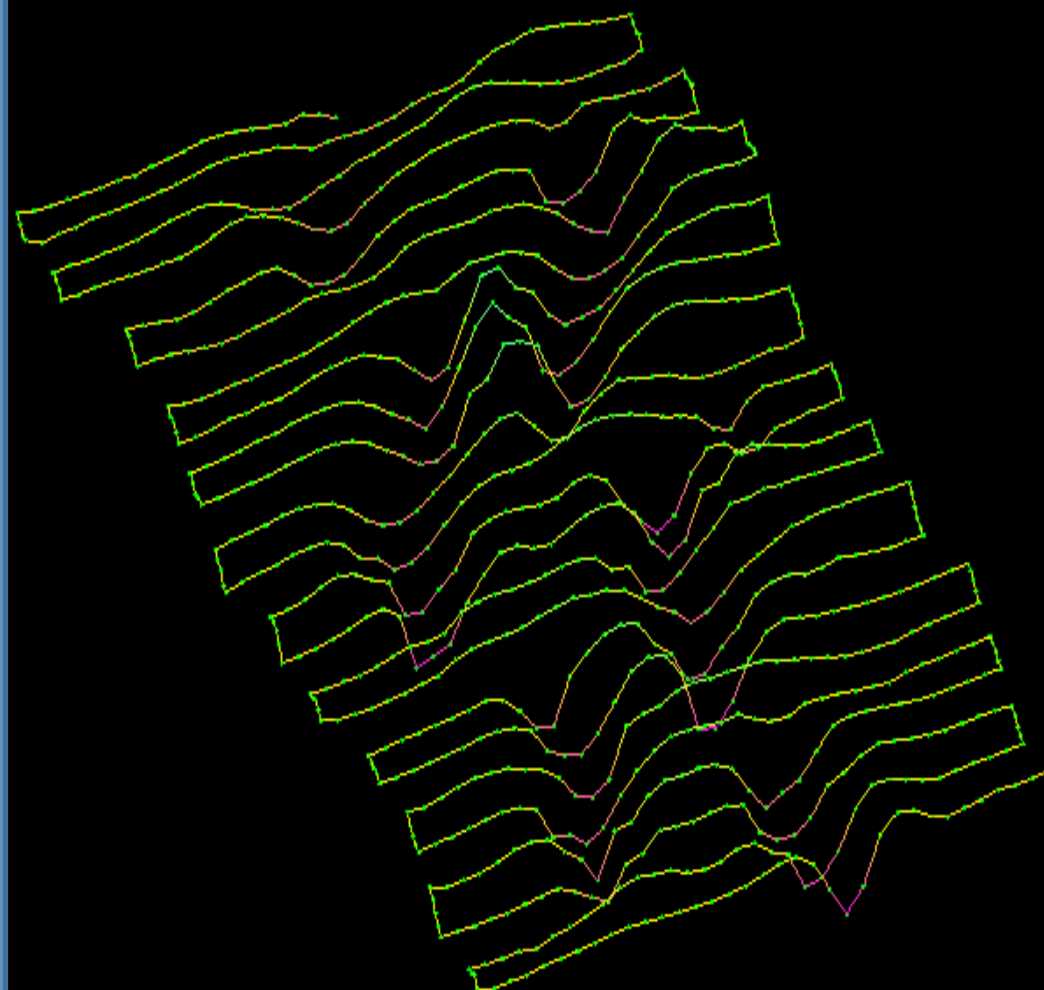
Computer Address	Channel #	Location on wing	Starting Fiber Bragg strain sensor
114.95	1	Right tip upper main spar	21
114.95	6	Right tip upper aft spar	17
114.95	5	Right tip lower main spar	19
114.95	4	Right mid upper main spar	19
114.95	3	Right mid upper aft spar	20
114.95	8	Right mid lower main and aft spar	19
114.95	2	Right center upper main and aft spar	19
114.95	7	Right Center lower main and aft spar	17
113.154	2	Left Center upper main and aft spar	18
113.154	1	Left Center lower main and aft spar	21
113.153	6	Left mid upper main spar	19
113.153	5	Left mid upper aft spar	19
113.153	1	Left mid lower main spar	20
113.153	2	Left mid lower aft spar	18
113.153	4	Left tip upper main spar	19
113.153	3	Left tip upper aft spar	19
113.153	8	Left tip lower main spar	18
113.153	7	Left tip lower aft spar	18

Other Projects Cont.



Global Observer Fuselage Fiber

Strain field of Aft Fuselage fiber during straight-line flight



Other Projects Cont.

- Impressing “The Suits”
  - Learning LabVIEW/fiber optics on the spot
- Medical Research and Pressure Questions
- Teachers
- Recruitment video

Thank you!

Parents

Russ Billings

Allen Parker

Patrick Chan

RS

Ron/Craig

Joanne

Fellow Students