FOSS (Fiber Optics Sensing System) at NASA AFRC - Overview

OPTICAL SENSORS FOR ENERGY APPLICATIONS

a l·ǸǑƘ нлно

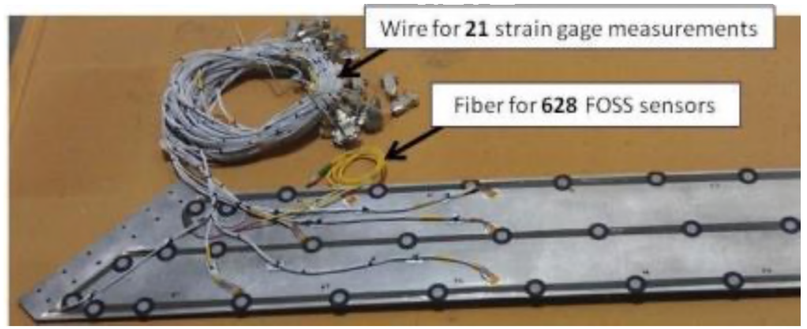
t l·ǘǸǰǑʅ l ƻƴ a l·ƴ /Ƙl·ƴ

ƘƻƴǆǑƘl·ƴƳ ƴЛ·ăl·ǆƎƻǾ

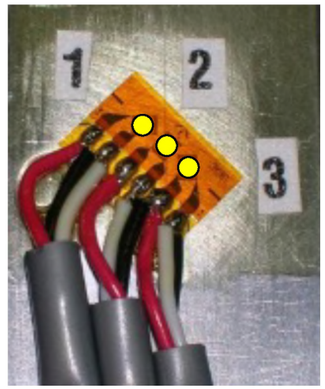
Table of Content

Why Choose Fiber Optic Sensors over Resistive Gages?

hyŜ hŦ ¢KŜăŜ ¢KƛyƎă óƛă bƨű [ƛ⟧Ŝ ¢KŜ hűKŜŊăú

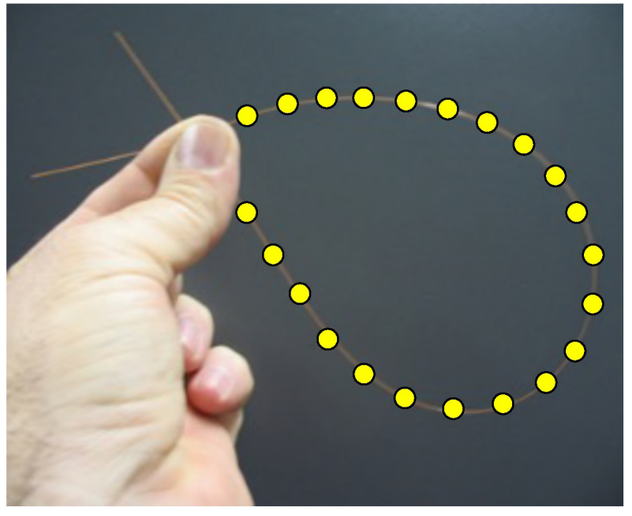


ó I ŜI·Øèú



ó . ƛƎú

ó I I·ŊŘú



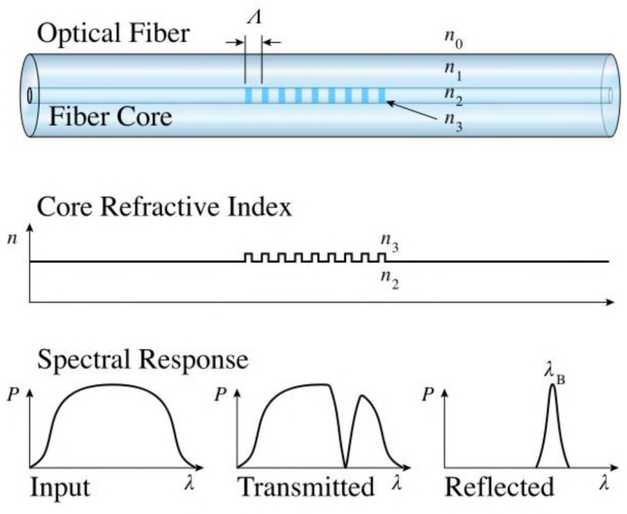
ó[ƛƎKűΣ ăY I·ffΣ ŜI·ăèú

Fiber Bragg Grating (FBG) as sensor

t NJλyǑλLJfŜ

Å CλōŜNJ wŜŦfŜŎűƨNJ űKIˑű NJŜŦfŜŎűă Iˑ
LJIˑNJűλŎdzfIˑNJ ø IˑØŜfŜyƎűK IˑyŘ
űNJIˑyãYλű Iˑff ƨűKŜNJă

Å .NJIˑƎƎ ² IˑØŜfŜyƎűKY ¦Ґн "Ş



a ŜIˑădzNJλyƎ {űNJIˑλyǒeú ƨNJ
¢ŜYLJŜNJIˑüdzNJŜ óD¢ú ØλIˑ C . D ăŜyãƨNJ

æ ! = ɾ(- ") + (# + $)φ
——
!

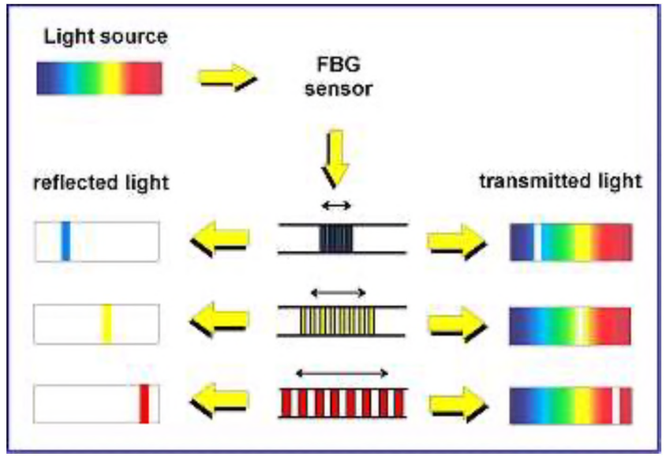
Å φ ¦Ґ ǑKIˑyƎŜ λY . NJIˑƎƎ ø IˑØŜfŜyƎűK ŘdzŜ
űƨ ŜyØλNJƨyYŜyűIˑf ǑKIˑyƎŜ

Å ¦Ґ LyλűλIˑf . NJIˑƎƎ ø IˑØŜfŜyƎűK ƨŦ C . D

Å „Ґ ăúNJIˑλyπƨLJűλŎă Ǒ2ŜŦŦλŎλŜyű

Å # Ґ ¢KŜNJYIˑf ŜÈLJIˑyãλ2YǑ2ŜŦŦλŎλŜyű

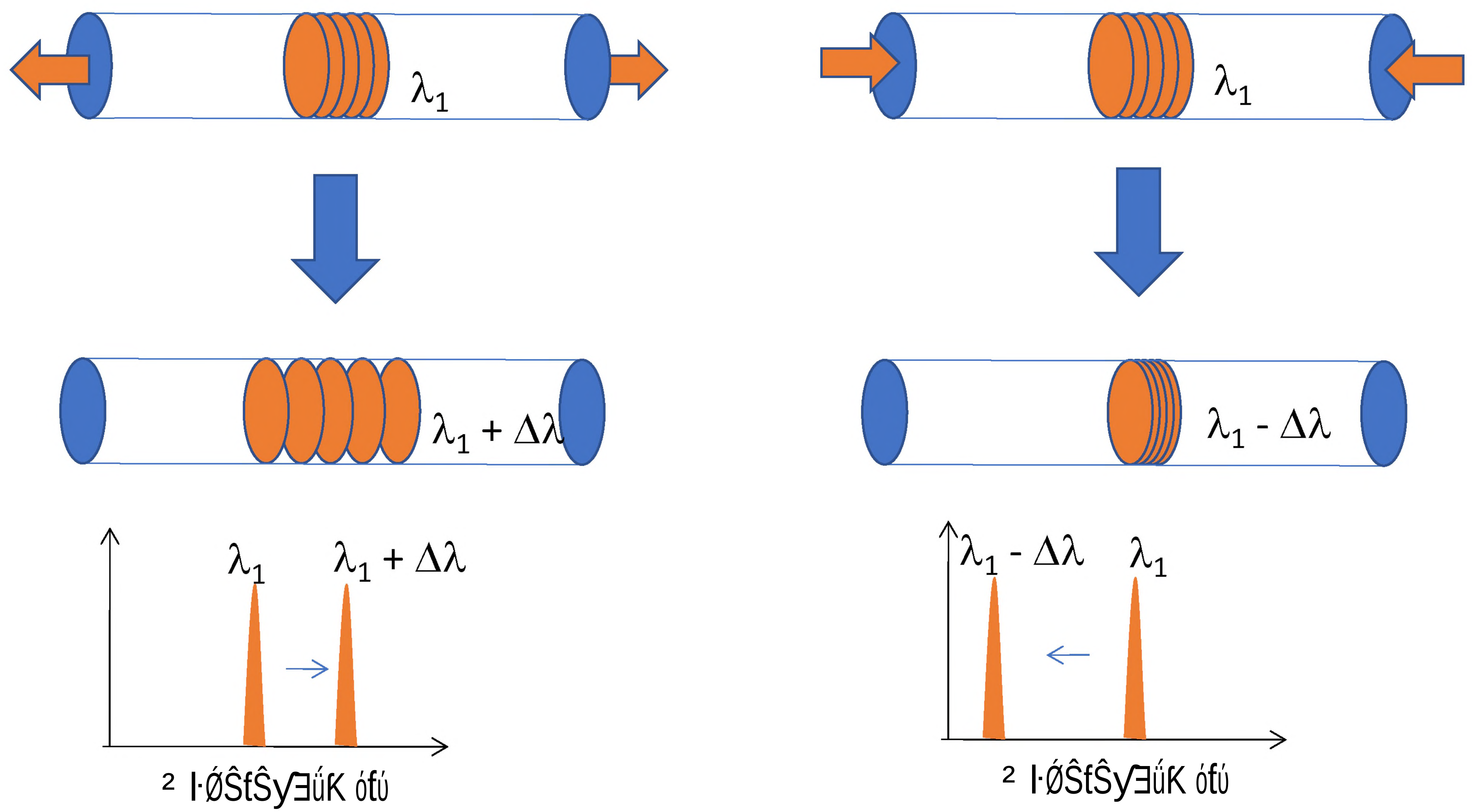
Å $ Ґ űKŜNJYƨπ2LJűλŎ Ǒ2ŜŦŦλŎλŜyű



ARMSTRONG
FLIGHT RESEARCH CENTER

How do FBG sensors works?

Å[ʎʅŜ l·yʃ l·ŎŎƻŊŘʎƻyʃŁ ŎKl·yƎŜ ʎyʃ .Ŋl·ƎƎ ² l·ǾŜſŜyƎŭK



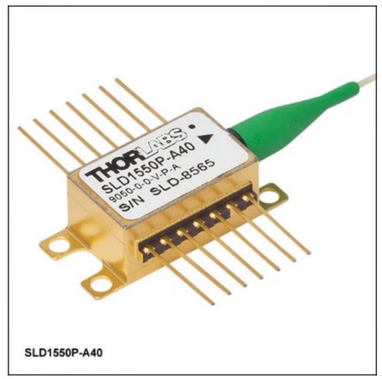
Typical FBG sensing via Wavelength Division Multiplexing (WDM)

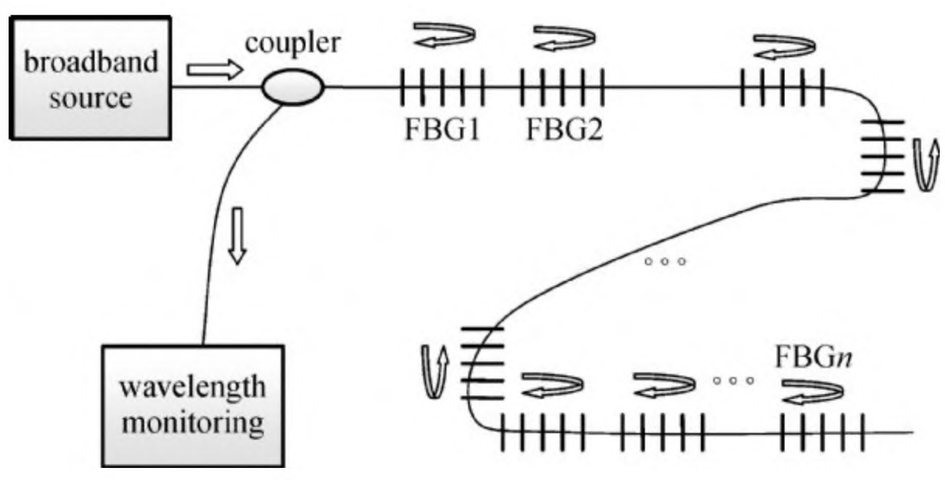
Å9ÈŎƛűI·űƛƨƴ{ƨdzNJŎŜ ófƛƎKű
ăƨdzNJŎŜú
Å [95
Å [I·ăŜNJ

ÅCƛōŜNJ {Ŝyãƨ NJă óC.Dú

Åtƙƨüƨ ŘŜűŜŎűƨNJ ó!ĸ5ú

Å5ŜűŜŎűƛƨƴ{ŎƘKŜYŜ óhLJűƛŎI·f
{LJŜŎűNJdzY !yI·fèÎŜNJú

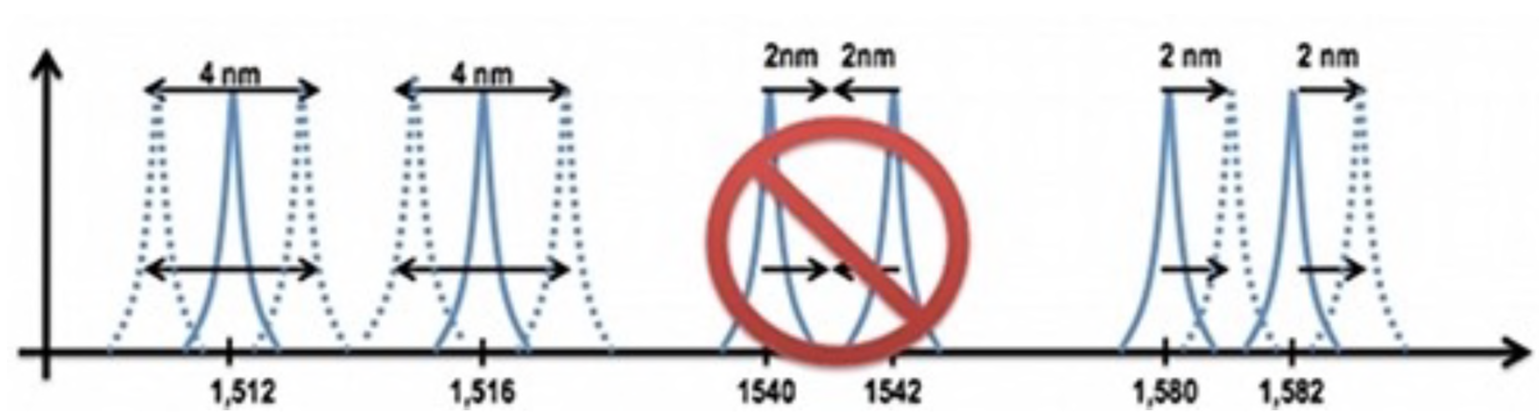




c

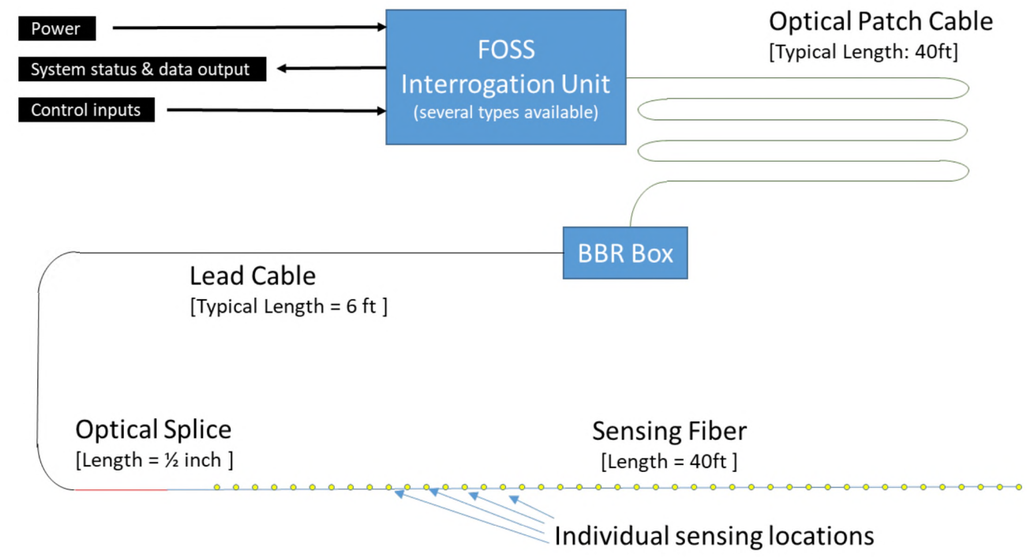
Pro/Con of WDM

- Å!ŘØl·ýűl·ƎŜ
  - Å{Ŝyǎ₴ǋă Ŏl·ý ōŜ ԿʅϒI·øl·è ŦǋȤϒ ʎýűŜǋǋȤƎl·űȤǋ
  - ÅwŜſl·űʎǾŜ {ʎϒǇſŜ aŜl·ădzǋŜϒŜyű
  - Å /ȤϒϒŜǋŎʎl·ffè !Øl·ʎſl·ōſŜ
  - ÅIʎƎK {l·ϒǇſʎýƎ {ǇŜŜŘ !Øl·ʎſl·ōſŜ όԿaIIύ
- 5ʎăl·ŘØl·ýűl·ƎŜ
  - ï [ȤŎl·űʎȤýȤŦ Ŝl·ŎK ăŜyǎȤǋ ϒl·űűŜǋă
  - ï 9l·ŎK ăŜyǎȤǋă Kl·ă űȤ Kl·ǿŜ dzýʎIjdzŜ øl·ØŜſŜyƎűK
  - ï hýſè Կмл ăŜyǎȤǋ Ŏl·ýȤŎŎdzǇʎŜŘ м Řl·űl· ŎKl·ýýŜſ
    - Å !ſʎl·ăʎýƎ ŜŦŦŜŎű
      - ï ² KŜýн ăŜyǎȤǋă ʎýűŜǋăŜŎűă Ȥ ýŜ l·ýȤűKŜǋ



NASAôs Unique FBG Interrogation Technique: OFDR

- Å hLJűλǑl·f CNJŜljdzŜyǑè 52Yl·λyʹwŜŦfŜǑű2YʹŜűNJè óhC5wúY
  - Å . l·ăŜŘ 2yʹfl·ăŜNJ λyʹűŜNJŦŜNJ2YʹŜűNJè
    - Å {λy∃fŜ [2y∃λűdzŘλyl·f Yʹ2ŘŜ fl·ăŜNJ yŜŜŘŜŘ
  - ÅLyØ2fØŜă ăλ∃yl·f LJNJ2ǑŜăăλy∃
    - Å C2dzNJλŜNJ ¢NJl·yʹãŦ2NJYʹkλyØŜNJăŜ C2dzNJλŜNJ ¢NJl·yʹãŦ2NJYʹ
  - Å ¦ăŜ øŜl·⟆ ℕŜŦfŜǑűλØλűè C . D
    - Å ¢èLJλǑl·f ² 5 a C . DΩă wΓyɬ⟆
    - Å ¢èLJλǑl·f hC5w C . DΩă wΓлϕлℙ⟆
  - Å{2 øKè dzăŜ hC5w Ŧ2ℕ ăŜyʹãλy∃ λyʹãűŜl·ŘK
    - Å a l·yè l·ŘØl·yűl·∃Ŝă űKl·ű ² 5 a Ǒl·yΩű Yʹl·űǑK



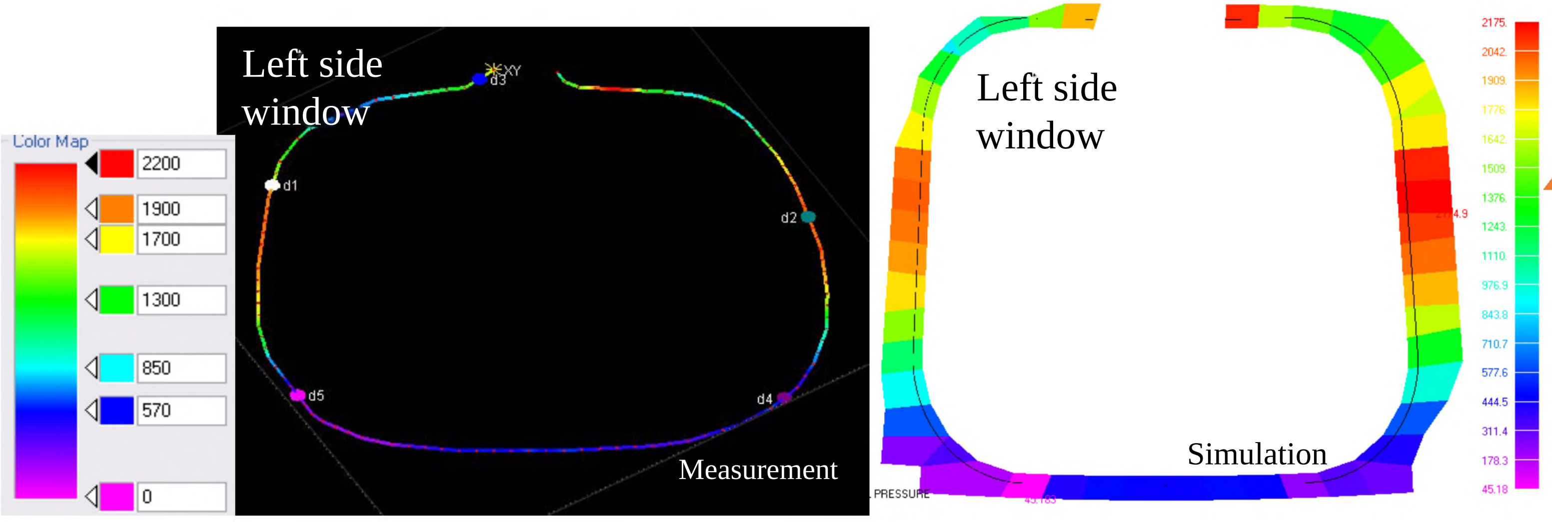
Advantage of OFDR over WDM

Å I ⅄ƎK {ǈI·Ű⅄I·f 5Ŝyã⅄űè ƻǿŜǊ ² 5 a ꞁōI·ăŜŘ ăŜyã⅄yƎ

Å ¦ ǈ űƻ млпл C . Dă ŎI·y ōŜ Y dzƭű⅄ ǈƭŜȄŜŘ ó h C 5 wú

Å ! ű Y ƻăű мл C . D ăŜyăƻǊă ǈŜǊ Ŧ⅄ōŜǊ ó ² 5 a ú

- C9 a űèǈŜ ƻŦ ŘI·űI· ŎI·y ōŜ I·ŎK⅄ ŜØŜŘ űKǊƻdzƎK ǊŜI·ƭπű⅄ Y Ŝ űŜăű⅄yƎ



Å / ƻăű ǈŜǊ ăŜyăƻǊ ƭŜyƎűK ⅄ă ŘǊI· Y I·ű⅄ŎI·ƭƭè ǊŜŘdzŎŜ Øă ² 5 a ꞁōI·ăŜŘ ăŜyăƻǊă

Å Þл¢трк C . D ó h C 5 wú I·ōƻdzű Þсл ŦƻǊ ул ăŜyăƻǊă

Å ÞНлпк C . D ó ² 5 a ú

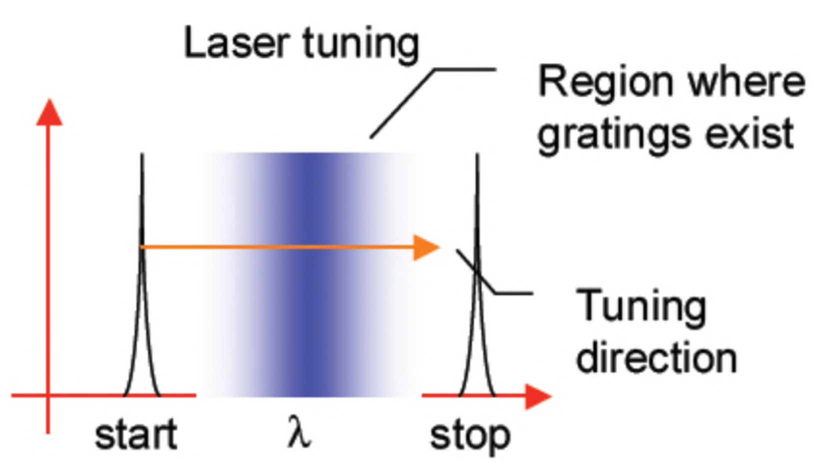
b ! { ! / ƻ Y ǈƻă⅄űŜ / ǊŜ ǿ a ƻŘdzƭŜ ¢Ŝăű ⅄yƎ ó Н л м м ú

Optical Frequency Domain Reflectometry

- All FBGs are written at the same wavelength (<), instead of each having a unique wavelength (WDM)
  - Multiplexing of hundreds of sensor in single fiber
- A narrowband wavelength tunable laser source is used to interrogate multiple sensors.
- Each FBG sensor is only İ inch long

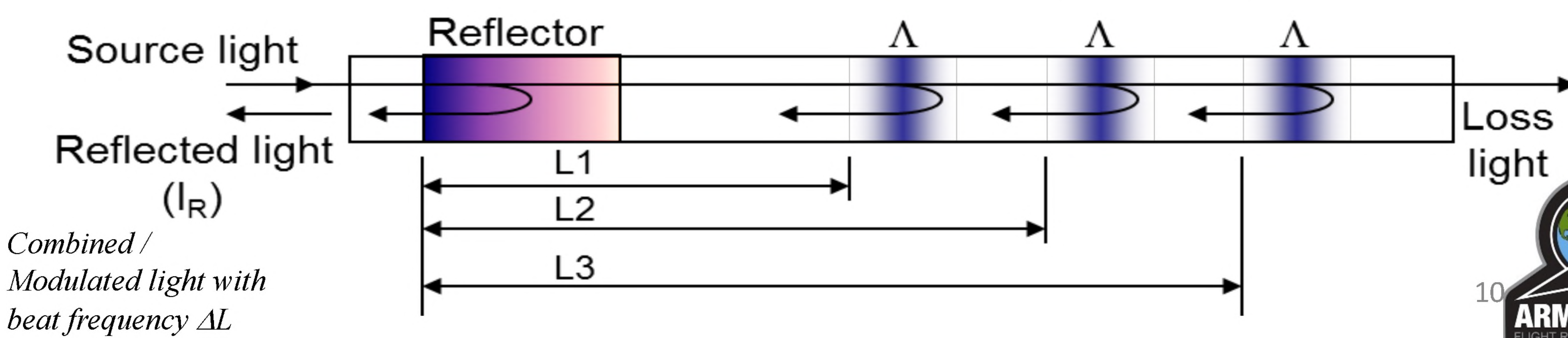
[illegible]

- [illegible]
  - [illegible]
- [illegible]
- [illegible]

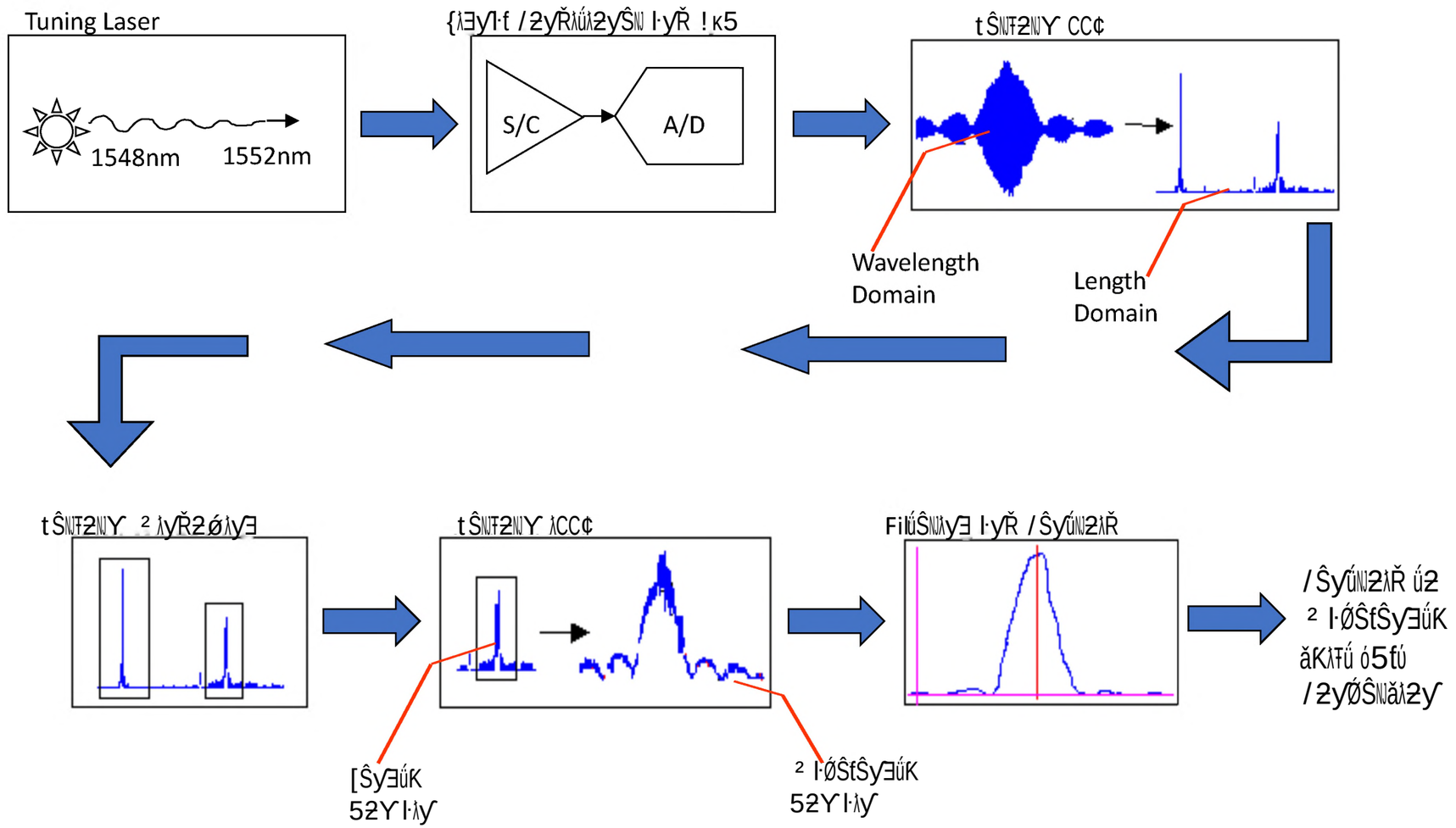


$$I_R = \sum_i R_i Cos(k 2 n_0 L_i) \qquad k = \frac{2\pi}{\lambda}$$

R_i – spectrum of i^{th} grating
n_0 – effective index
L – path difference
k – wavenumber



Flow-chart: OFDR Signal Processing (Pre-sensor)



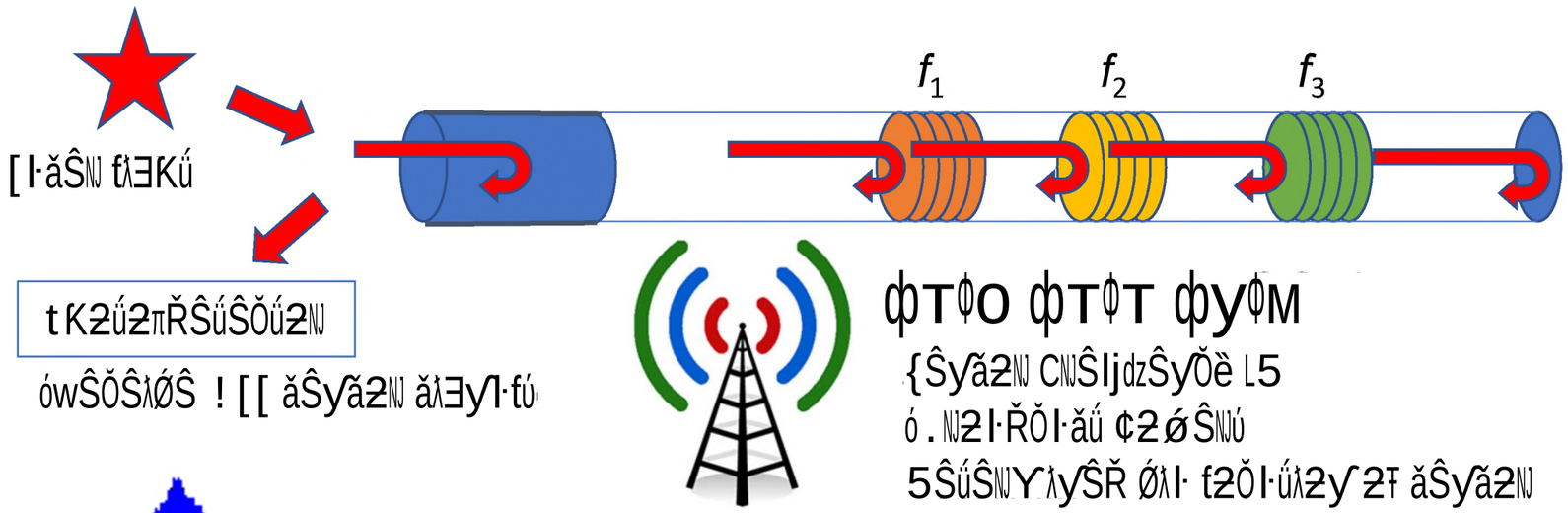
Laymanôs Term: Tuning your favorite radio station !

wl·Řƛ2 ₦ŜŎŜƛØŜă ! [[₮₦ŜljdzŜyŎƛŜă

Ña dzťűĂĻJťŜ ₮₦ŜljdzŜyŎƛŜă
l·₦Ŝ ō₦2l·ŘŎl·ăűŜŘ 2y l·ƛ₦ø l·ØŜ

wl·Řƛ2 űdzyŜ₦ l·ŎŎŜLJűă hb9 ₮₦ŜljdzŜyŎè

Radio analogy to Optical Frequency Domain Reflectometry



[l·ăŜNJ fƛƎKű

tK₂ű₂πŘŜűŜŎű₂NJ

ówŜŎŜƛØŜ ![[ăŜyã₂NJ ăƛƎyl·fú

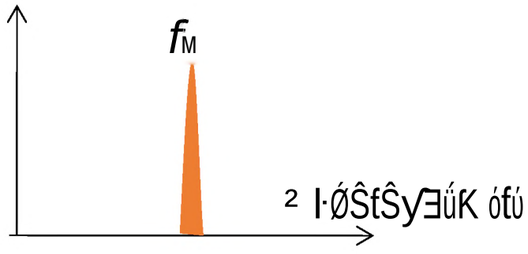
ϕTϕO ϕTϕT ϕyϕM

{Ŝyã₂NJ CNJŜljdzŜyŎè L5

ó.NJ₂l·ŘŎl·ăű ¢₂øŜNJú

5ŜűŜNJYƛyŜŘ ØƛI· f₂ŎI·űƛ₂y₂ŦăŜyã₂NJ

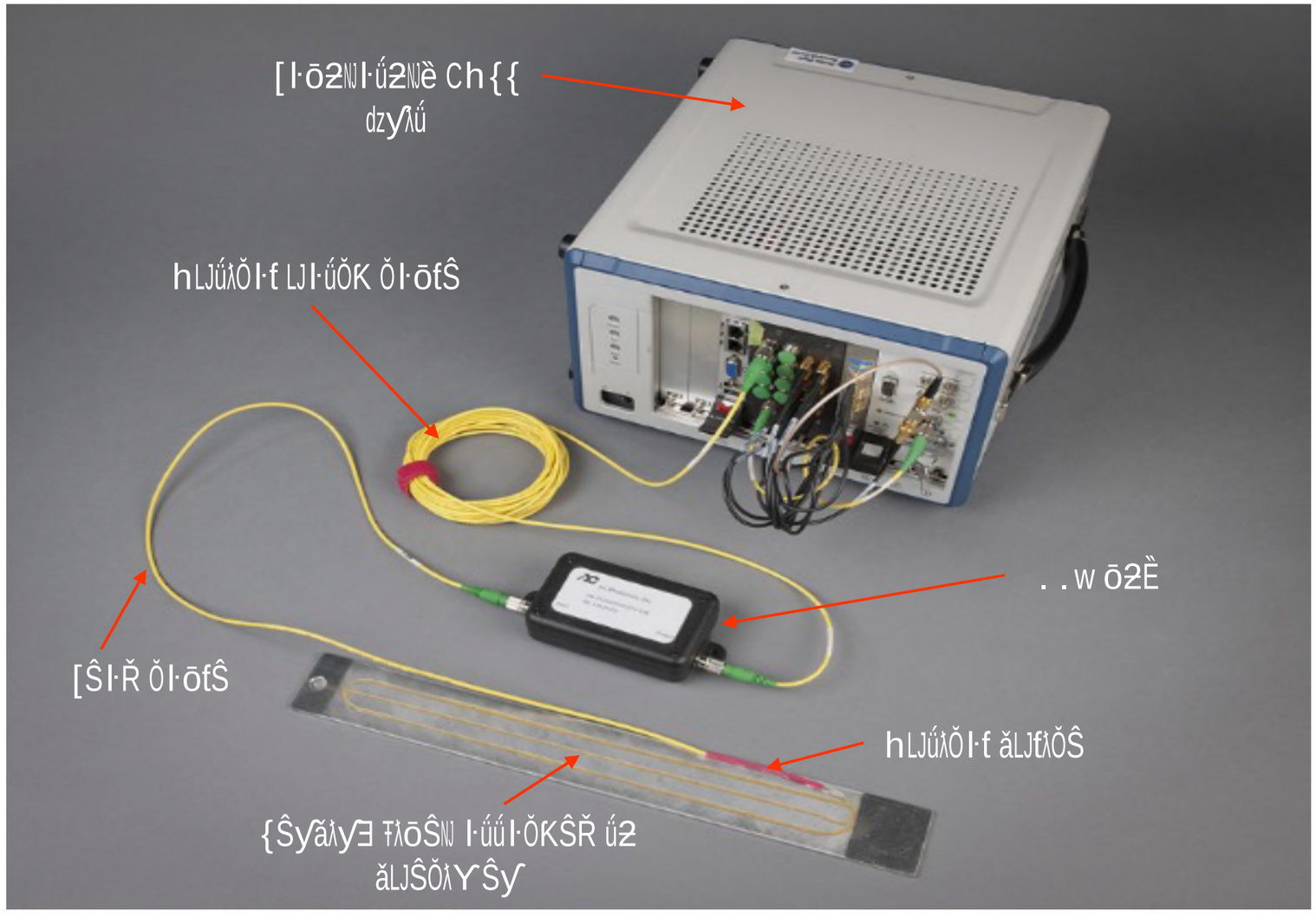
ówl·Řƛ2 wŜŎŜƛØŜNJú



CC¢κƛCC¢ ű2 áŘƛl·f ƛyɛ ű2 LJl·NJűűƛŎdzfl·NJ ăŜyã₂NJ ƛyŦ₂NJYl·űƛ₂y

ówl·Řƛ2 ¢dzyŜNJú

Ch{{ /ƨYLJƨyŜyűă



AFRCôs Current FOSS Capabilities

Current system specifications

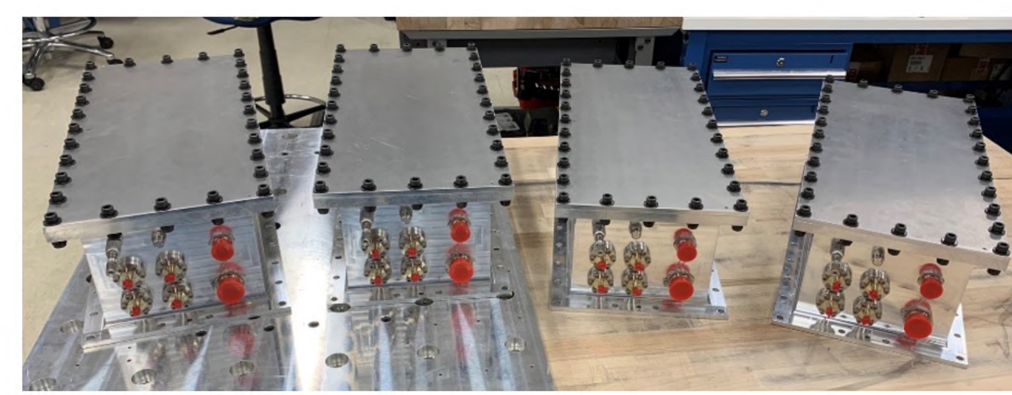
Fiber channels	2 to 4 to 8
Max sensing length / fiber	40 ft
Max sensors / fiber	2000
Fiber type:	SMF-28
Max sample rate (flight)	50 Hz
Power (flight)	28VDC @ 4.5 Amps
Power (ground)	110 VAC
User Interface	Ethernet
Weight (flight, non-optimized)	27 lbs
Weight (ground)	7 to 25 lbs
Weight (launch)	35 lbs
Size (flight, non-optimized)	7.5 x 13 x 13 in
Size (ground, latest)	10 x 4 x 6 in
Size (launch)	19.25 x 9 x 6.25 in

Aircrafts supported: Predator-B, Global Observer, G-III



Cf\3Kǘ {èǎǘŜY


DN2dzyŘ {èǎǘŜYǎ

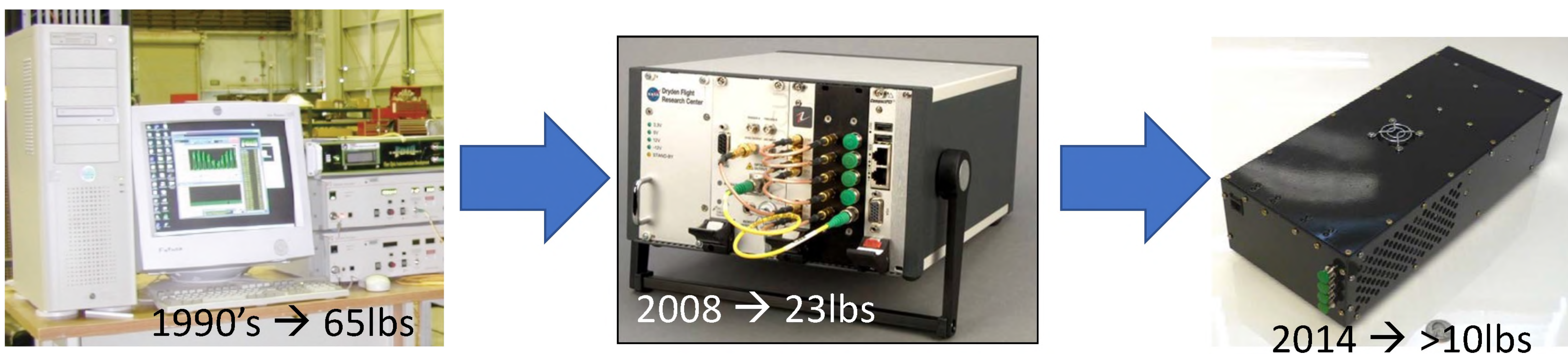


[l·dzyŎK {èǎǘŜY

AFRC's role in fiber sensing technology

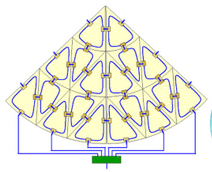
Å¢ŜŎKyƻfƻƎè ʎă ŦʎNJăű
ǇʎƻyŜŜNJŜŘĸǇŀűŜyűŜŘ ŀű b ! { !
[ŀyƎfŜè wŜăŜŀNJŎK /ŜyűŜNJ ó[ŀw/ú
ŘdzNJʎyƎ űKŜ fŀűŜ флΩăY
  - Å [ŀōƻNJŀűƻNJèπōŀăŜŘ ăèăűŜY
  - Å hyŜ ăŀYǇfŜ ōŜʎyƎ űŀʅʎyƎ ŜøŜNJè
    ол ăŜŎƻyŘ óƻyŜ ŎKŀyyŜfú

- AFRC miniaturized and developed an "one-box system" for aerospace application
  - Compact system for flight or ground test
  - Patented improved sampling rate to 100 samples per second (multiple channels)



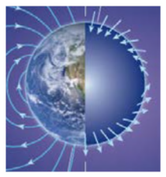
tŀNJʅŜNJ ¦{ tŀűŜyű yΣмлλΣору

FOSS Fields of Operation



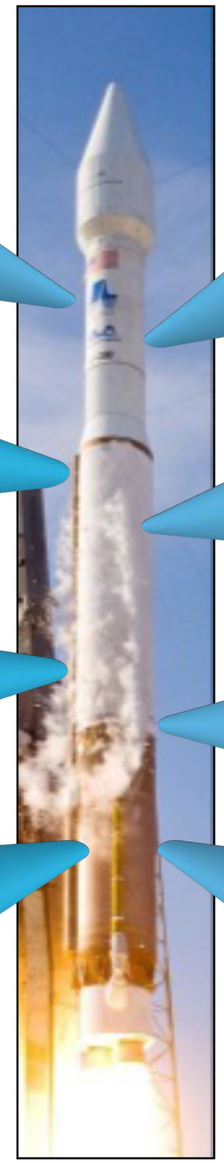
¢t{ lŜl·fűK
a2yʌűƵNJʌyƎ

9Yōŝřřŝř
{űNJl·ʌy



a l·ƎyŜűʌŏ CʌŜfř

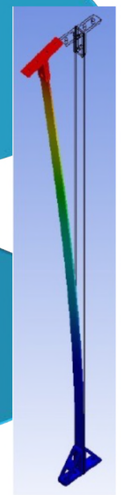
! LJLJfʌŜř [2l·Řă



{űNJl·ʌy

¢ŜYLJŜNJl·ůdzNJŜ l·yŘ
/NJè2ƎŜyʌŏ
[ʌljdzʌŘ [ŜØŜf

н5 {Kl·LJŝ

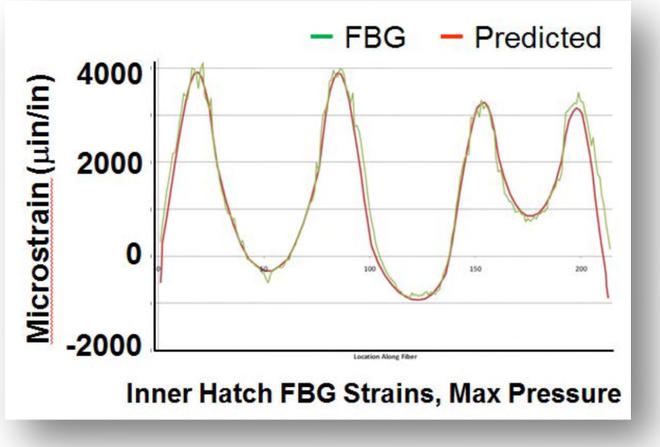


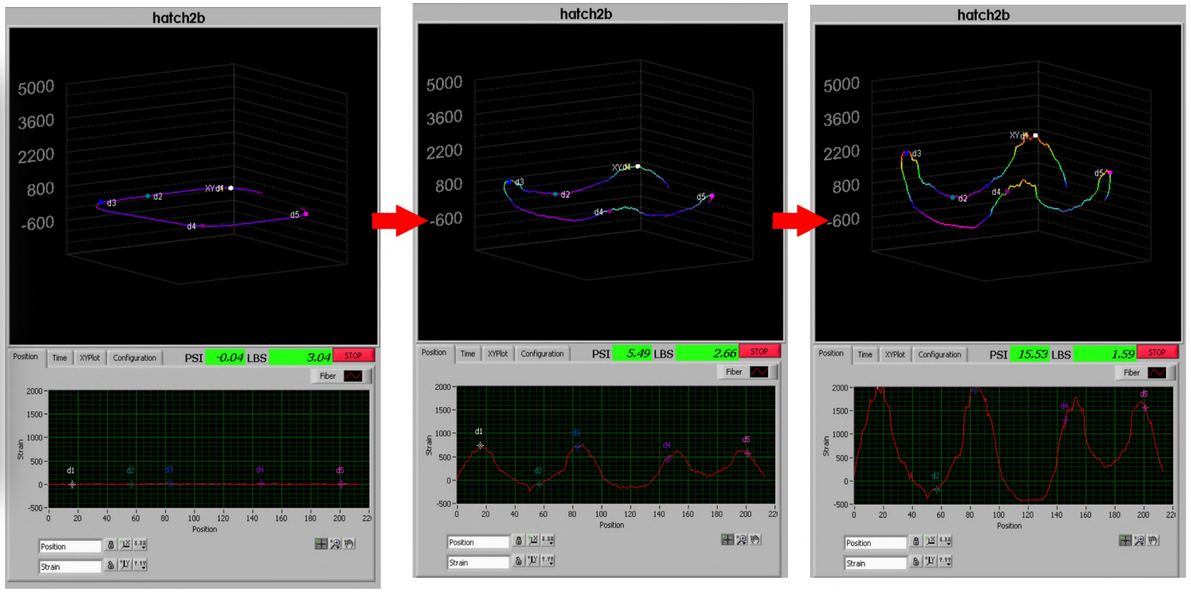
o5 {Kl·LJŝ

MT

Composite Crew Module - NESC

- ω C2dzNJ ŦλōŜNJă ǿŜNJŜ λyãűl·ffŜŘ l·NJ2dzyŘ űKŜ Y2ŘdzfŜΩă űKNJŜŜ ǿλyŘ2ǿă l·yŘ 2yŜ Kl·ŰŎK
- ω wŜl·fπűλYŜ o5 ăúNJl·λyŤŘλăúNJλōdzűλ2yã ǿŜNJŜ Ŏ2ffŜŎűŜŘ l·ă űKŜ Y2ŘdzfŜ dzyŘŜNJǿŜyű нлƒ̂ː 5[[LJNJŜăădzNJλÎl·űλ2yťűŜăűλyƎ
- ω aŜl·ădzNJŜŘ ăúNJl·λyã Ŏ2YLJl·NJŜŘ l·yŘ Yl·ŰŎKŜŘ ǿŜff űƲ LJNJŜŘλŎűŜŘ Y2ŘŜf NJŜădzfűă
- ω tNJƲ2ŜŎű /2yŎfdzăλ2yŸ
  - ω ǻǻCλōŜNJ 2LJűλŎă NJŜl·f űλYŜ Y2yλű2NJλyƎ 2Ŧ űŜăű NJŜădzfűă l·Əl·λyãű l·yl·fèűλŎl·f LJNJŜŘλŎűλ2yã ǿl·ă ŜăăŜyűλl·f λyťűKŜ ădzŎŎŜää 2Ŧ űKŜ Ŧdzffπ ăŎl·fŜ űŜăű LJNJƲƎNJl·Yφε
  - ω ályťl·NJŜl·ă 2Ŧ KλƎK ăúNJl·λyťƎNJl·ŘλŜyűă űKŜăŜ űŜŎKyλljdzŜă ǿŜNJŜ λyØl·fdzl·ōfŜφε





Cryogenic Liquid Level-Sensing using cryoFOSS

Å ¢ĸŜ /ĸl·ffŜy∃Ŝ

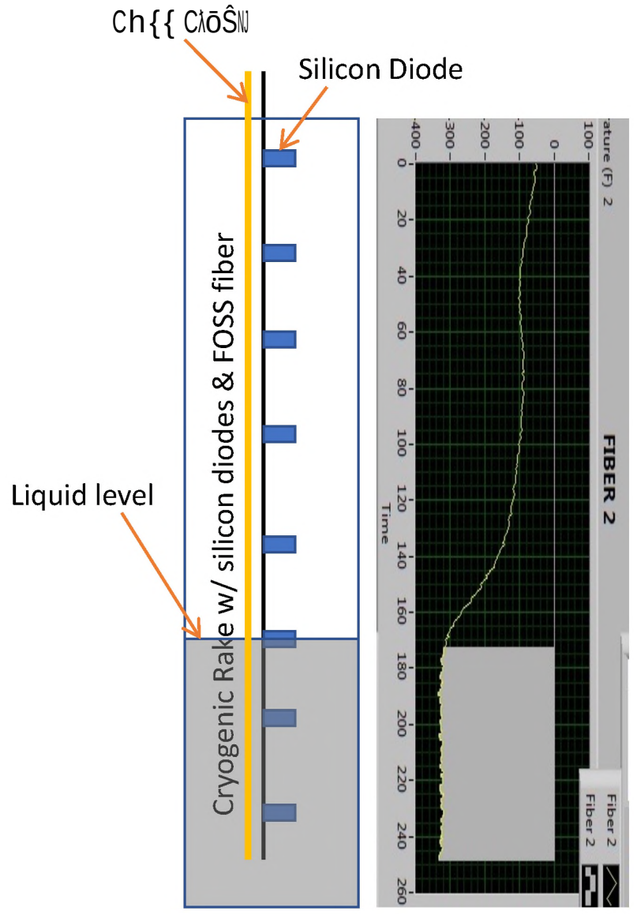
- Å ¢ĸŜ űɴ̃l·yãλűλ2yl·f LJĸl·ăŜ ōŜűøŜŜy fλljdzλŘ l·yŘ ∃l·ă 2ŧ Ŏɴ̃è2∃Ŝyλŏă λă ŘλŧŧλŎdztű ű2 ŘλăŎɴ̃λYλyl·ûŜ øĸλfŜ Yl·ʅλy∃ fλljdzλŘ fŜØŜf YŜl·ădzɴ̃ŜYŜyűă
- Å ¦ ăλy∃ ŘλăŎɴ̃ŜűŜ Ŏɴ̃è2∃ŜyλŎ űŜYLJŜɴ̃l·űdzɴ̃Ŝ Řλ2ŘŜă ălJl·ŎŜŘ l·f2y∃ l·ɴ̃l·ʅŜ èλŜfŘă Ŏ2dzɴ̃äŜ ălJl·ûλl·f ɴ̃Ŝă2fdzűλ2y 2ŧ fλljdzλŘ fŜØŜf

Å Ch{{ ! LJLJɴ̃2l·ŎK

- Å ² KλfŜ dzăλy∃ l·ySYz2YŜűɴ̃è YŜűK2Ră ûĸŜ ûɴ̃l·yãλűλ2yl·f LJĸl·ăŜ Ŏl·y ōŜ Yl·LJLJŜŘ ōŜűűŜɴ̃
- Å ¦ ăλy∃ l· ăλy∃fŜ Ŏ2yűλyʤz2dză ∃ɴ̃l·ûλy∃ ŧλōŜɴ̃ KλƎK ălJl·ûλl·f ɴ̃Ŝă2fdzűλ2y Ŏl·y ōŜ l·ŎKλŜØŜ

Å ! LJLJfλŎl·ûλ2yãY

- Å [l·dzyŎK ØŜKλŎfŜă
- Å {l·űŜffλűŜă
- Å /λØλf {ûɴ̃dzŎûdzɴ̃Ŝă
- Å Dɴ̃2dzyŘ ¢Ŝăûλy∃.
- Å /h t± ō2ûűfŜă

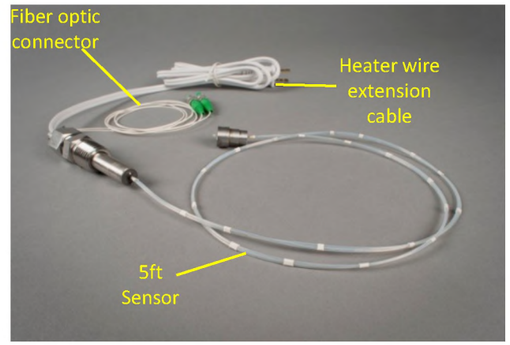


/ɴ̃è2∃SyλŎ /2yűl·λyŜɴ̃ Ch{{ ¢Ŝăű wŜădztűă

/ɴ̃è2∃SyλŎ /2yűl·λyŜɴ̃ f2Ŏl·ûŜŘ l·ű a{C/ óōŜf2ø ŘŜŎʅú

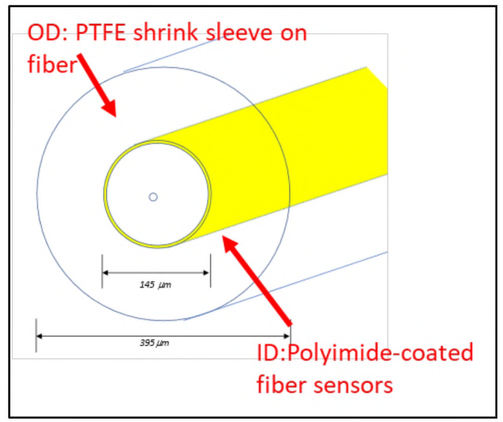
¢ø2 ¢èLJŜă 2ŧ Ŏɴ̃è2Ch{{ ăŜyã2ɴ̃ă

Å ! ŎűλØŜ ăŜyã2ɴ̃ă çØλl· Ŏ2πf2Ŏl·ûλy∃ KŜl·ûλy∃ øλɴ̃Ŝ



tl·ɴ̃ʅŜɴ̃ Wɴ̃ Ŝű l·f£ ¦{t флтпфнм

Å tl·ăăλØŜ ăŜyã2ɴ̃ă ç Øλl· ŜyKl·yŎŜŘ /¢9 Øl·fdzŜă 2ŧ l· t¢C9 ăfŜŜØŜ



b ! { ! k¢ a πнлнлрллфспp

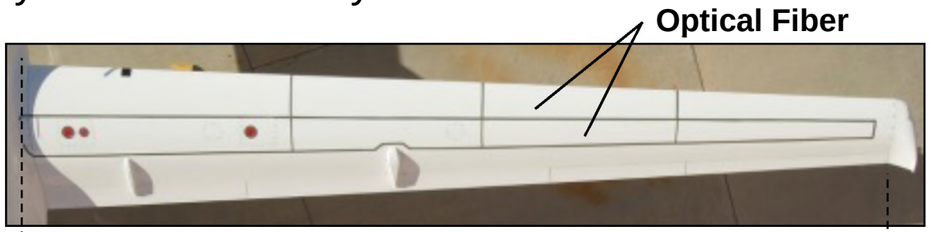
Example of Flight Validation - Predator-B (Ikhana) Flight Testing

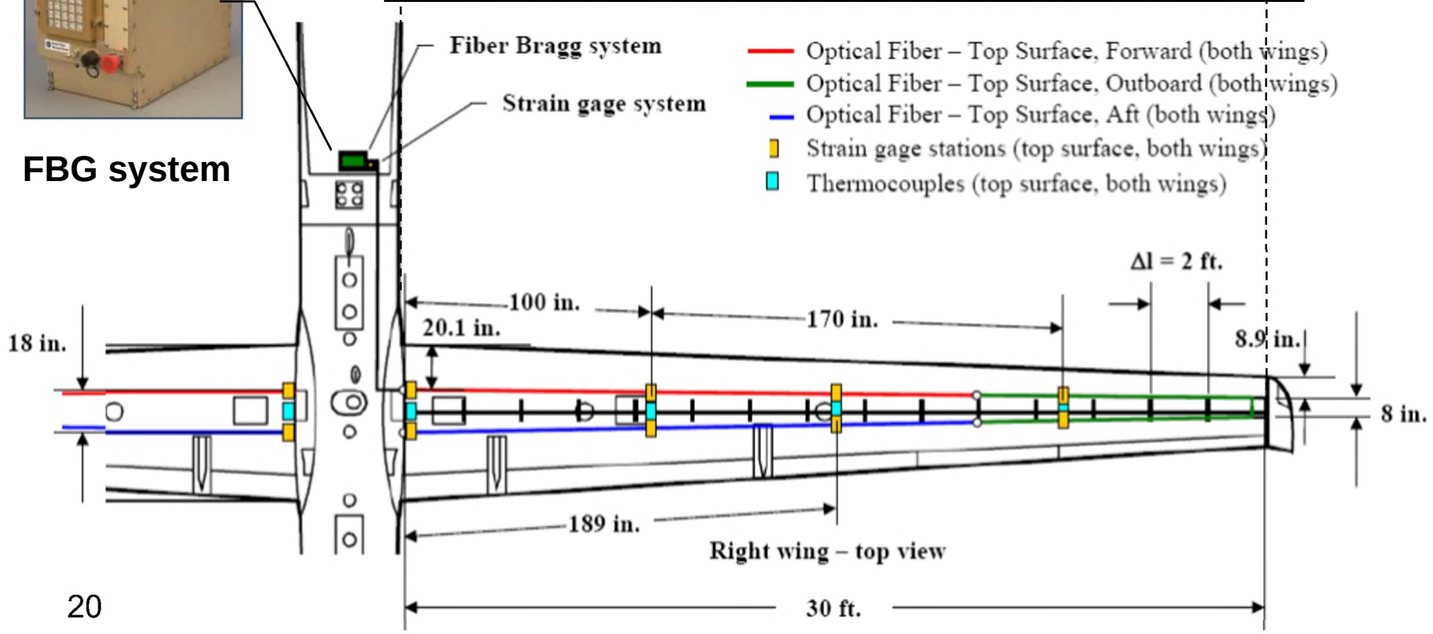
ÅLyãúNJdzY^ŜyűI·ůλ2y^

- Å нуул C . D ăűNJI·λy^ăŜyã2NJă ómфнл NJŜŎ2NJŘŜŘ I·ű 2yŜ ůλY^Ŝú
- Å мппл C . D ăŜyã2NJă LJŜNJ ølyƎ
- Å ¦ăŜNJπăŜfŜŎűI·ōfŜ yƍzY^ōŜNJ 2Ŧ C . D ăŜyã2NJă Ŧ2NJ NJŜI·fπűλY^Ŝ ølyƎ ăKI·LJŜ ăŜyãλyƎ
  - мс ăűNJI·λy^ƎI·ƎŜă Ŧ2NJ C . D ăŜyã2NJ ØI·fλŘI·ůλ2y^
  - y úKŜNJY^2Ŏ2dzLJfŜă Ŧ2NJ ăűNJI·λy^ăŜyã2NJ ŜNJNJ2NJ Ŏ2NJNJŜŎűλ2yã

Strain gage system

FBG system



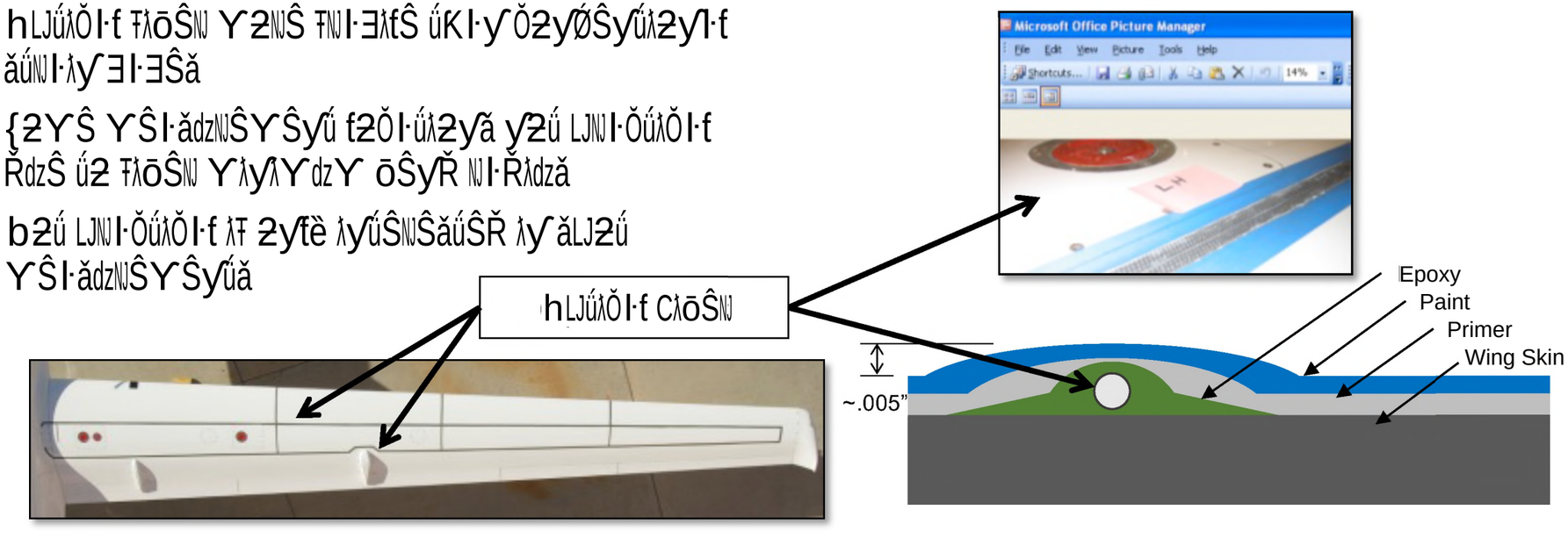


Lγãűl·ffl·űλ2γ ! ŘØl·γűl·ƎŜă

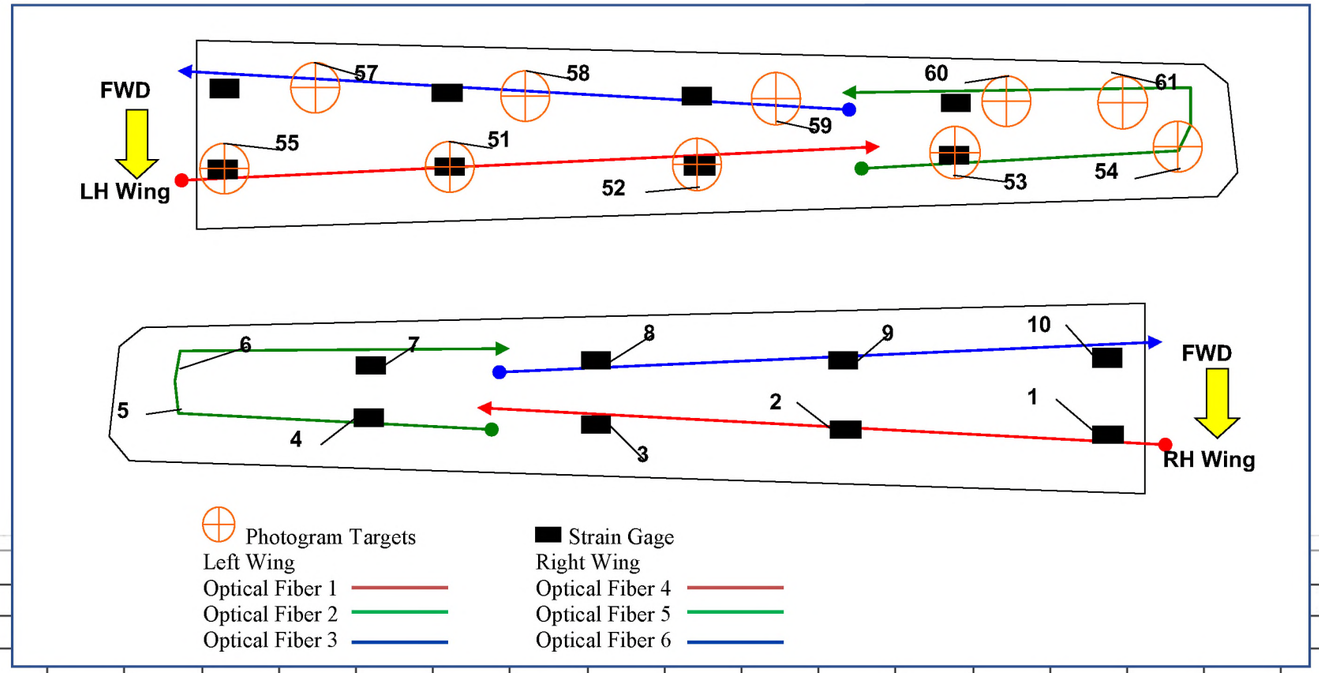
- Å DNJŜl·űfê NJŜŘdzŎŜŘ λγãűl·ffl·űλ2γűλΥŜ Ŏ2ΥLJl·NJŜŘ ű2 Ŏ2γØŜγűλ2γl·f ăűNJl·λγƎl·ƎŜă
  - Å н Υl·γŘl·èă ₮2NJ плΩ ₮λōŜNJ óнллл ăűNJl·λγăŜγã2NJă ₮2NJ l· Ŏ2γűλγdz2dză ădzNJ₮l·ŎŜ NJdzγŭ
  - Å a dzfűλLJfŜ ăŜγã2NJă λγãűl·ffŜŘ ăλΥdzfűl·γŜ2dzăfê
  - Å {l·ΥŜ ădzNJ₮l·ŎŜ LJNJŜLJl·NJl·űλ2γ l·yŘ l·ŘĸŜăλØŜă l·ă Ŏ2γØŜγűλ2γl·f ăűNJl·λγƎl·ƎŜă
  - Å aλγλΥl·f űλΥŜ ălJŜyű ø2NJ]λγƎ 2γØŜKλŎfŜ
  - Å ! ff Ŏ2γγŜŎű2NJă Ŏl·γōŜ l·ŘŘŜŘ LJNJλ2NJ ű2 λγãűl·ffl·űλ2yΣ l·ø l·è ₮NJ2Υ LJl·NJű
  - Å b2 ă2fŘŜNJλγƎΣ γ2 Ŏfl·ΥLJλγƎ LJNJŜăădzNJŜ NJŜljdzλNJŜŘ
- Å / l·γōŜ λγãűl·ffŜŘ 2γ l·ŜNJ2Řèγl·ΥλŎ ădzNJ₮l·ŎŜă øλűK fλűűfŜ ű2 γ2 λΥLJl·Ŏű 2γ LJŜNJ₮2NJΥl·γŎŜ

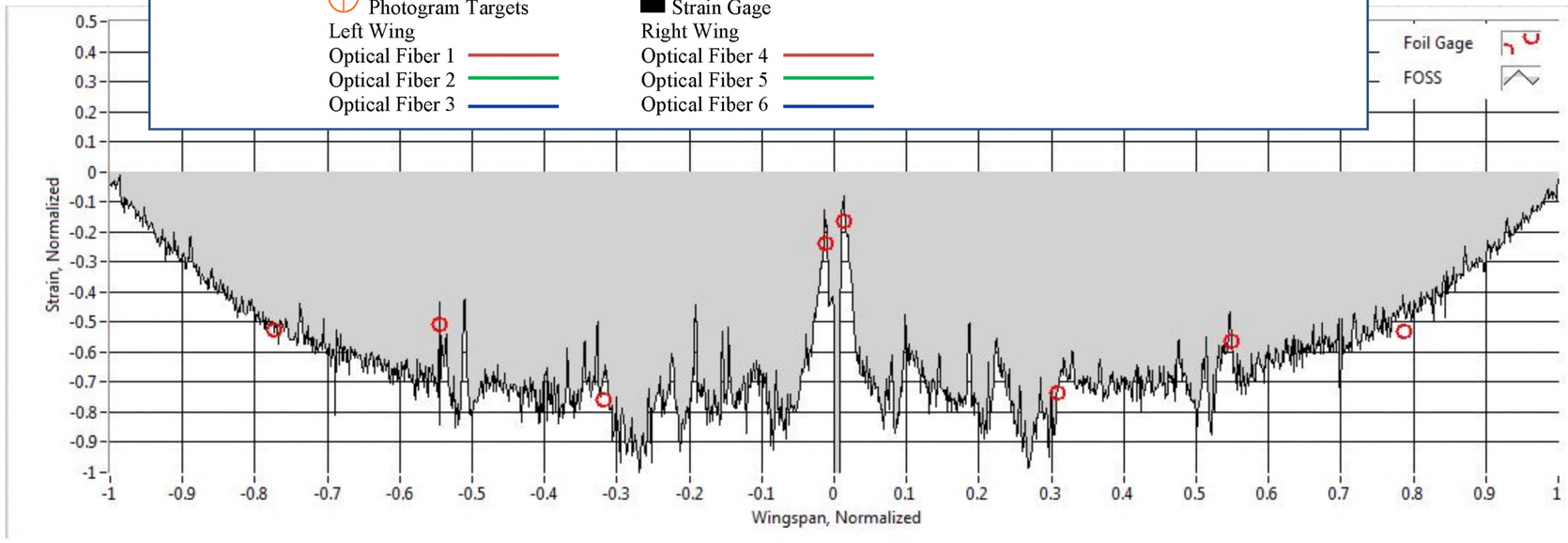
Lγãűl·ffl·űλ2γ /ĸl·ffŜγƎŜă

- hLJűλŎl·f ₮λōŜNJ Υ2NJŜ ₮NJl·ƎλfŜ űKl·γŏ2γØŜγűλ2γl·f ăűNJl·λγƎl·ƎŜă
- {2ΥŜ ΥŜl·ădzNJŜΥŜγű f2Ŏl·űλ2yã γ2ű LJNJl·ŎűλŎl·f ŘdzŜ ű2 ₮λōŜNJ Υλγλdz Υ ōŜyŘ NJl·Řλdză
- b2ű LJNJl·ŎűλŎl·f λ₮ 2yfè λγűŜNJŜăűŜŘ λγ ălJ2ű ΥŜl·ădzNJŜΥŜγűă



Flight Test Validation - Ikhana



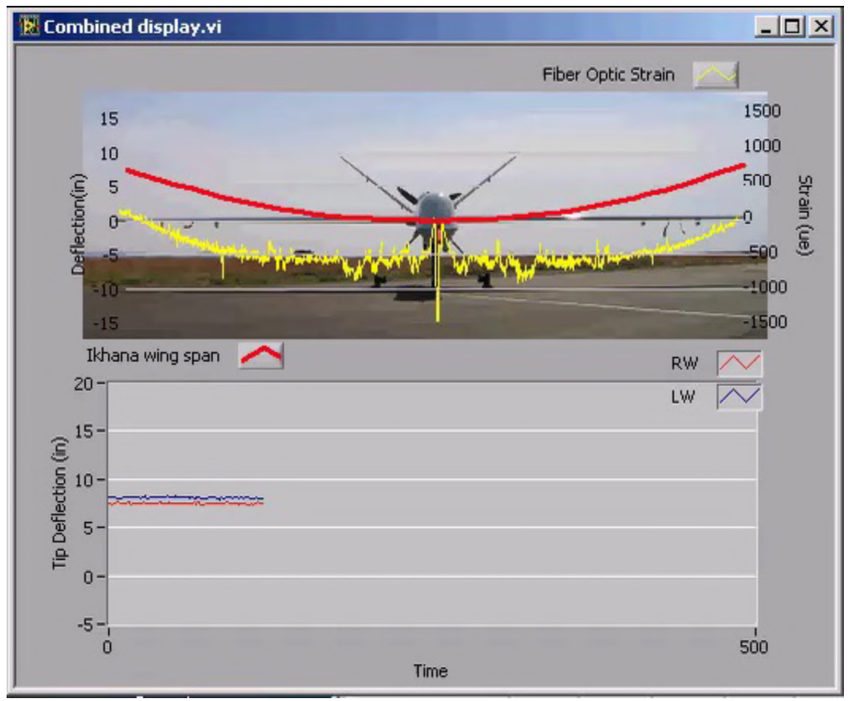


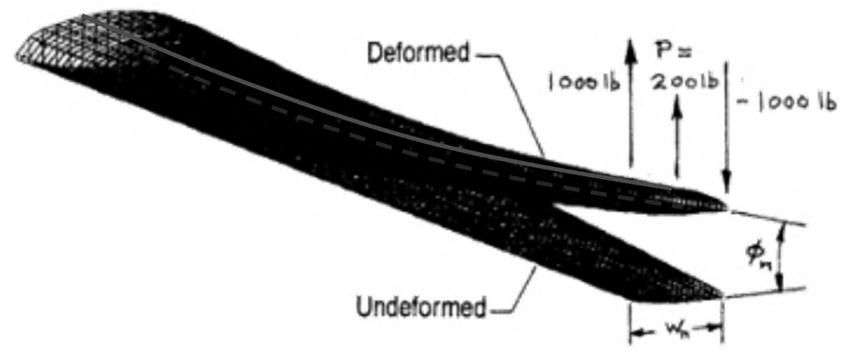
Structural Algorithms using FOSS

Å{űŃJdzŎűdzŃJl·f {ĸl·LJŜ

Å wŜl·fπűλYŜ ǿλyƎ ăĸl·LJŜ YŜl·ădzŃJŜYŜyű dzăλyƎ ŦλōŜŃJ ƨLJűλŎă ăŜyãƨŃJă

ÅóYƨΣ wλŎĸl·ŃJŘăT tl·űŜyű τΣτмpΣφφπú





² λyπűλLJ ŘŜŦfŜŎűλƨyYŜl·ădzŃJŜYŜyű ƨŢ·
!Cw/Ωă tŃJŜŘl·ű2Ń . ØλI· Ch{{

Å 9ÈűŜŃJyYl·ffè l·LJLJfλŜŘ fƨl·Řă

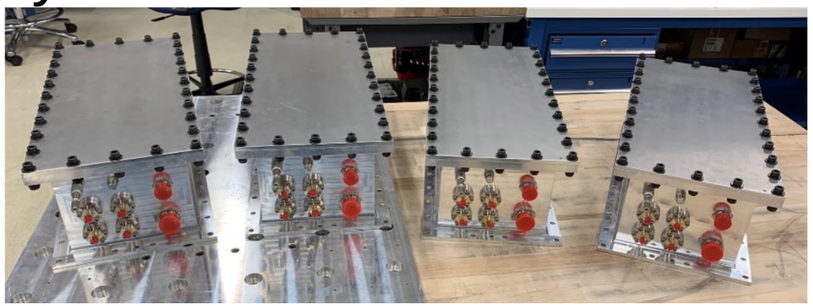
Å wŜl·fπűλYŜ l·LJLJfλŜŘ fƨl·Řă ƨyŎƨYLJfŜÈ ăűŃJdzŎűdzŃJŜă dzăλyƎ ŦλōŜŃJ ƨLJűλŎ ăŜyãƨŃJă

ówλŎĸl·ŃJŘăΣ Yƨτ tl·űŜyű τΣpнлΣмτcú

FOSS project - LOFTID

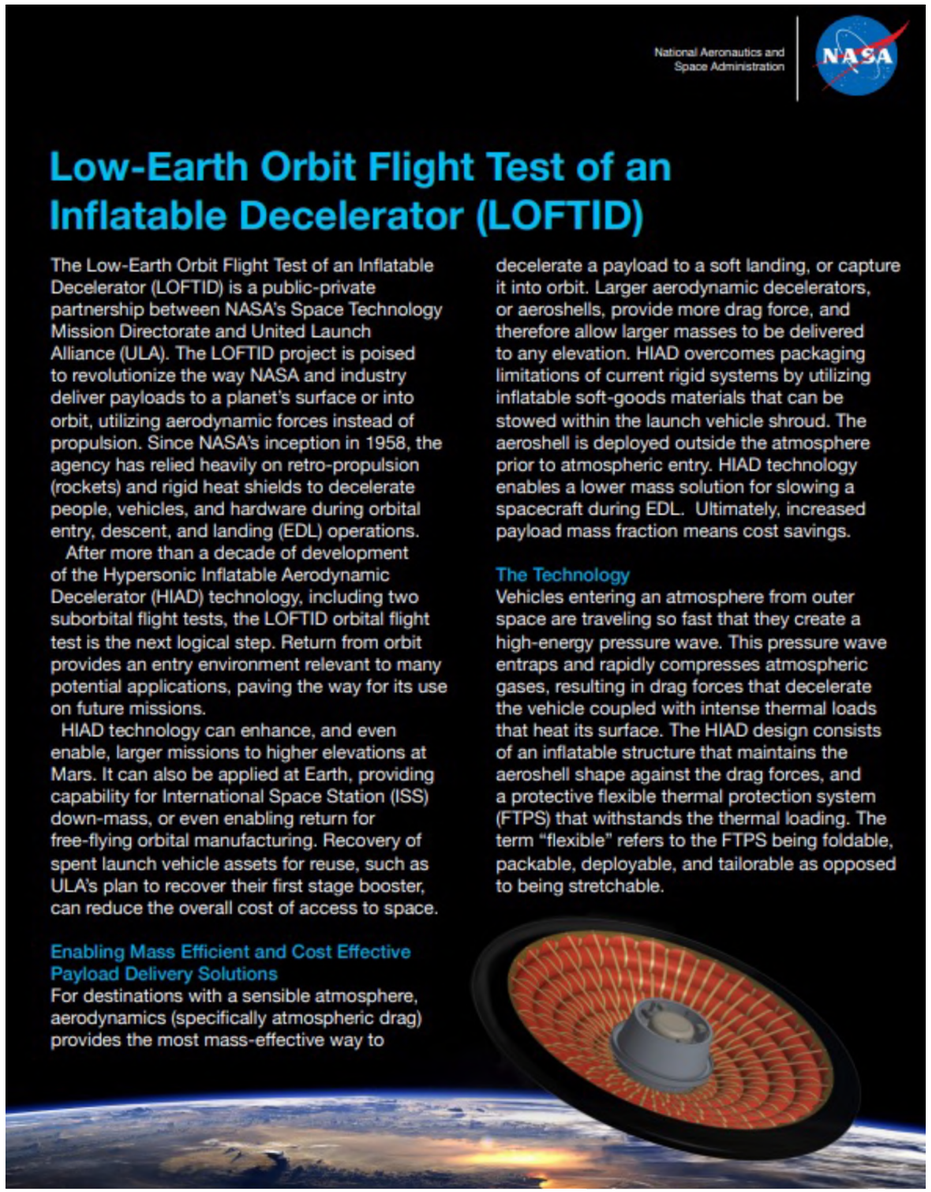
Å ! ƒl·dzƳǑK ǑJ·LJl·ǫfŜ ØŜNJăƛƨƳƨŦ Ch{{ ƛă
ōŜƛƳƎ ŘŜØŜf2LJŜŘ ü2 ădzLJLJƨNJú [hC¢L5

ÅCh{{ ƛă ƛƳűŜƎNJl·űŜŘ ƛƳű2 [hC¢L5 ű2
Ƴ2ƳƛűƨNJ Ƴ2ăŜπO2ƳŜ űSƳLJŜNJl·üdzNJŜ ŘdzNJƛƳƎ
NJŜŜƳűNJè



ÅÇh{{ Ǒ2ƳŘdzǑűŜŘ l·yŘ LJl·ăă l·ff
ŜyØƛNJƨƳƳŜyűl·f üŜăűƛƳƎ
Å9 aL űŜăűƛƳƎ
Å. dzNJƳπLƳ
Å¢KŜNJƳl·f Øl·ǑdzdzƳ ǑèǑfƛƳƎ ó¢± ! / ú
Å±ƛōNJl·űƛ2ƳűŜăűƛƳƎ

Å[l·dzƳǑKŜŘ 2Ƴ b2Ø мᵃᵘ нлнн

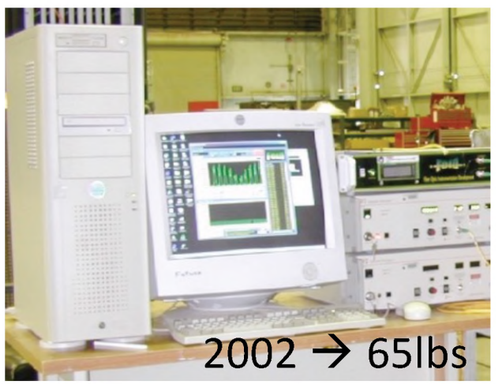


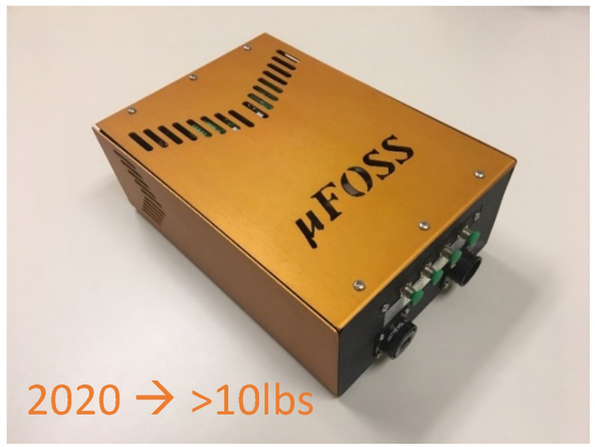
ARMSTRONG
FLIGHT RESEARCH CENTER


¢ŕKŜ ŕKŜl·ű ăKʎŜfŘ ŜyűŜNJŜŘ űŕKŜ l·űY2ăLJKŜNJŜ
l·ű ƨdzăü 2ØŜNJ мyΣллл Y'ʎfŜă LJŜNJ Ŕ2dzNJΦΦΦ

Summary

- b ! { ! ! Cw / Kl·ă ădzŎŎŜăăŦdzftê ŘŜØŜf2LJŜŘ ŦλōŜℕ 2LJűλŎă ăűℕl·λy˘ăŜyã2ℕă óCh{{ú űŜŎKy2f2∃è ŦℕZY˘ fl·ō2ℕl·ű2ℕè ű2 ℕŜl·fπø2ℕfŘ l·LJLJfλŎl·ûλ2y˘





Å/2Y˘Y˘ŜℕŎλl·fλÎl·ûλ2y˘2Ŧ ûŜŎKy2f2∃è λă 2yπ∃2λy∃ Øλl· b ! { ! ¢ŜŎKy2f2∃è ûℕl·yãŦŜℕ

- Å ! Ŝℕ2ălJl·ŎŜ {ŜŎű2ℕ
- Å 9yŜℕ∃è {ŜŎű2ℕ
- Å .λ2Y˘ŜŘλŎl·f {ŜŎű2ℕ