Active Flight Load Alleviation Using Segmented Trailing Edge Wings on a Small UAS

By

Benjamin Martins

California Space Grant Consortium

NASA Dryden Flight Research Center, Aeronautics Academy 2013

University of California, San Diego, La Jolla, CA 92093

Presented at:

National Council of Space Grant Directors' Spring Meeting, Arlington, VA

February 28th, 2014

California Space Grant CONSORTIUM

Overview

- Introduction
  - Aeronautics Academy Team
  - Objectives
  - Technologies
- System Description
  - Aircraft
  - Fiber Optic Sensor System
  - Segmented Control Surfaces
- Testing
  - Analytical Modeling
  - Flight Test Preparations
  - Flight Tests
- Results

California Space Grant CONSORTIUM

Overview

- Introduction
  - Aeronautics Academy Team
  - Objectives
  - Technologies
- System Description
  - Aircraft
  - Fiber Optic Sensor System
  - Segmented Control Surfaces
- Testing
  - Analytical Modeling
  - Flight Test Preparations
  - Flight Tests
- Results

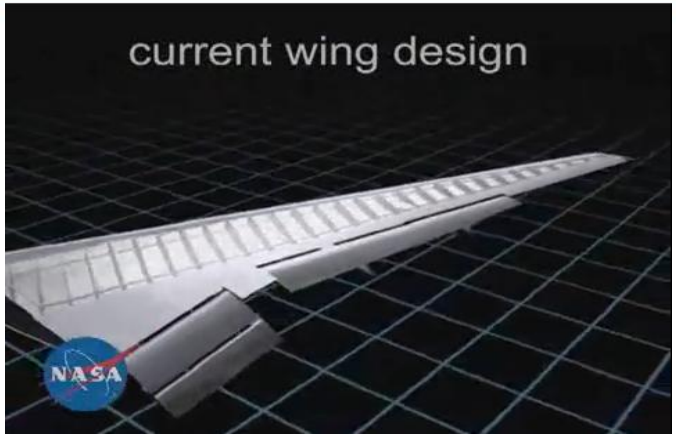
California Space Grant CONSORTIUM

Team Members

- Benjamin Martins
  - University of California, San Diego
    California Space Grant Consortium
- Nathan Suppanade
  - California State University, Los Angeles
    California Space Grant Consortium
- Corbin Graham
  - The University of Oklahoma
    Oklahoma Space Grant Consortium

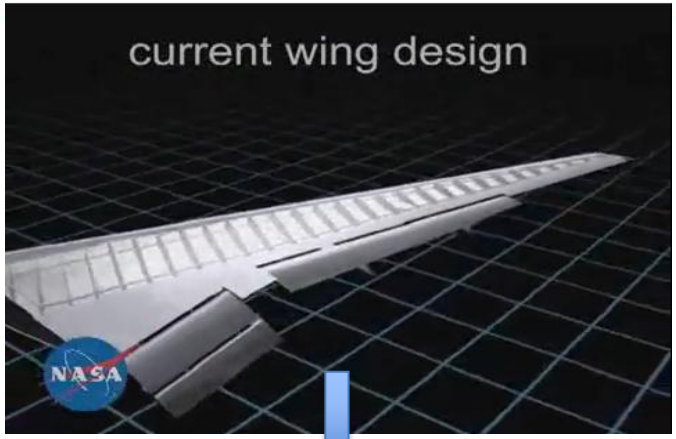
California Space Grant
CONSORTIUM

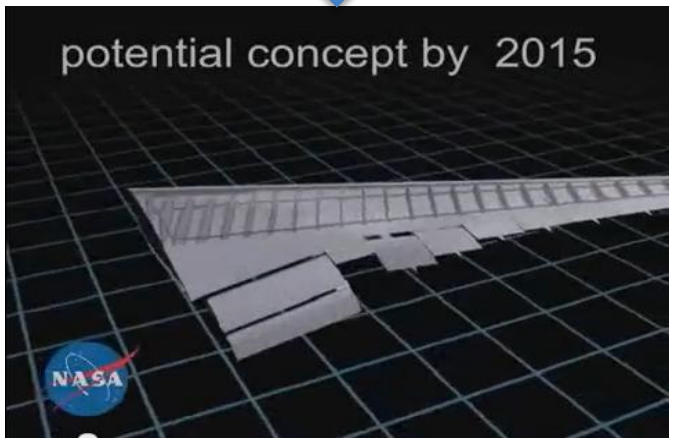
Introduction



California Space Grant
CONSORTIUM

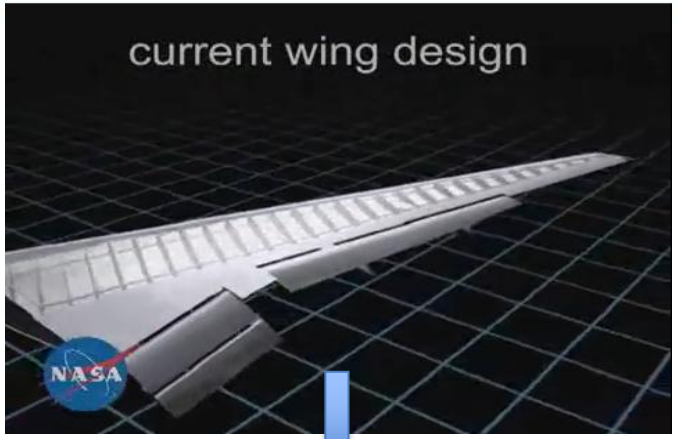
Introduction

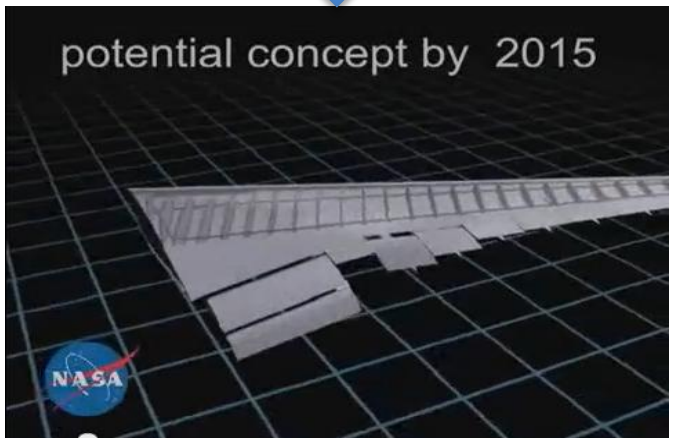


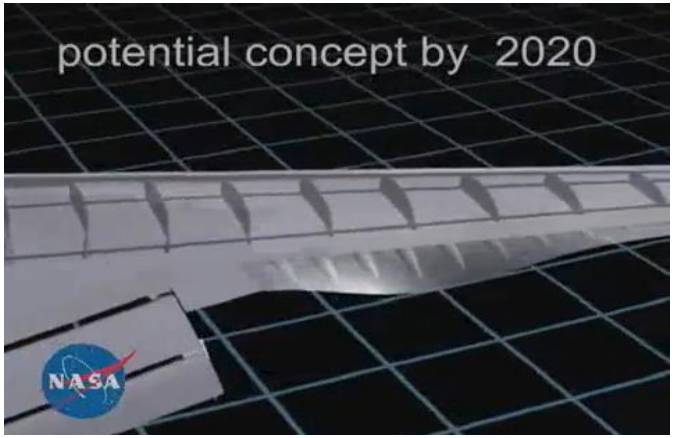


California Space Grant
CONSORTIUM

Introduction

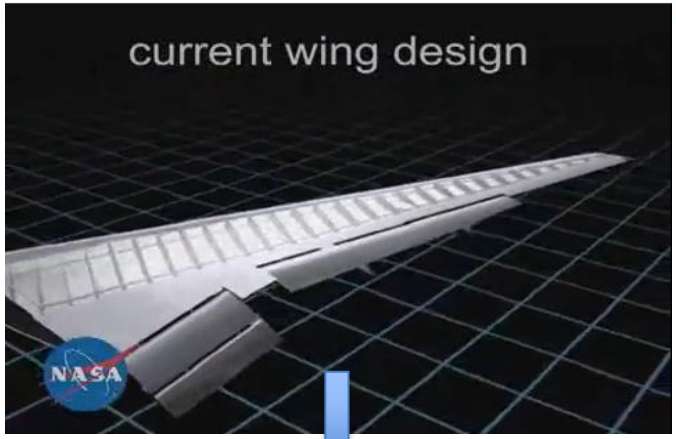


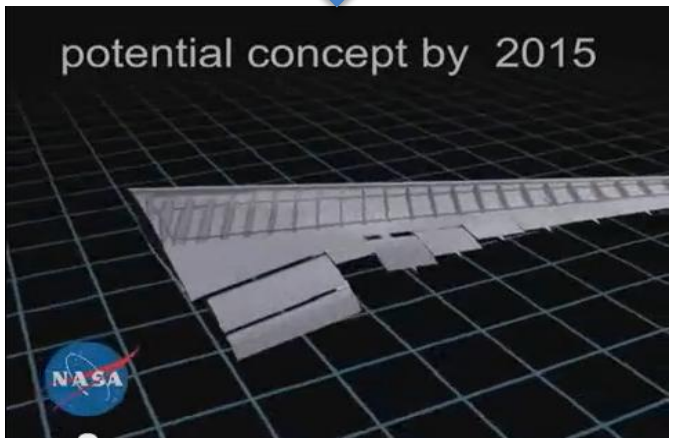


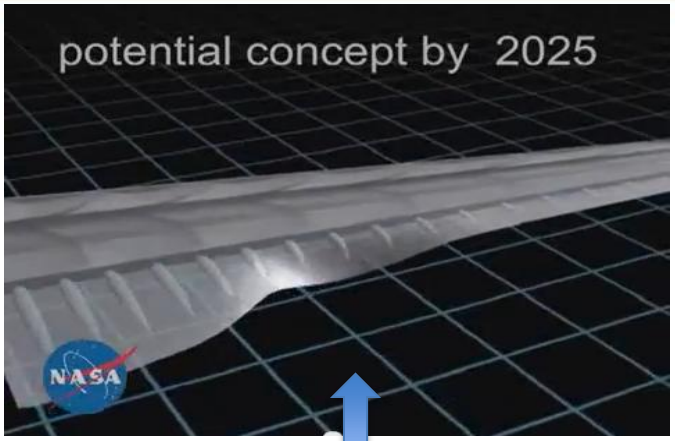


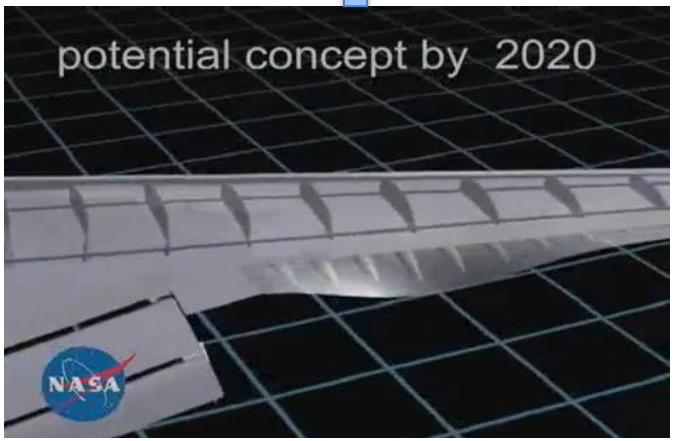
California Space Grant
CONSORTIUM

Introduction



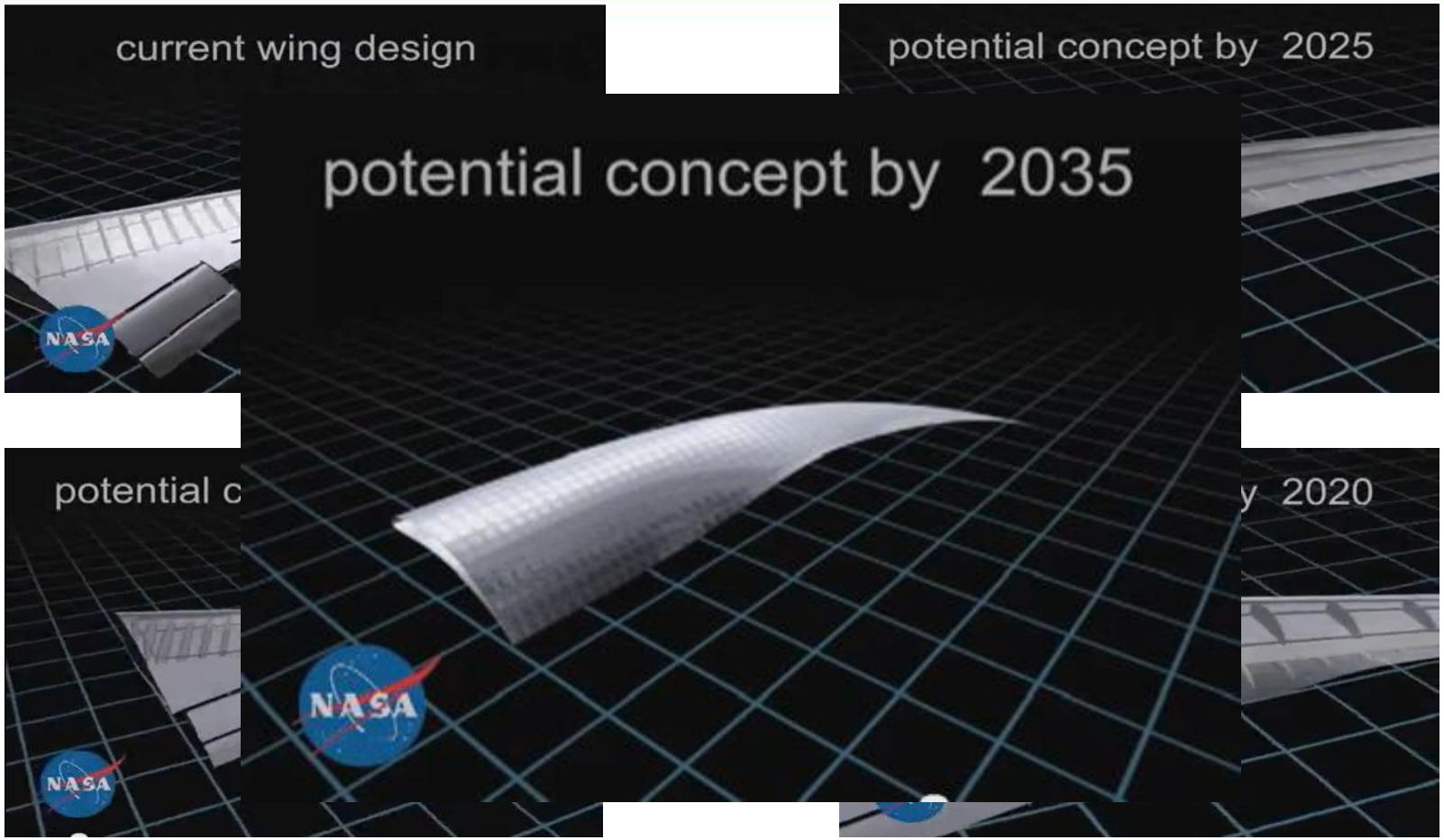






California Space Grant
CONSORTIUM

Introduction



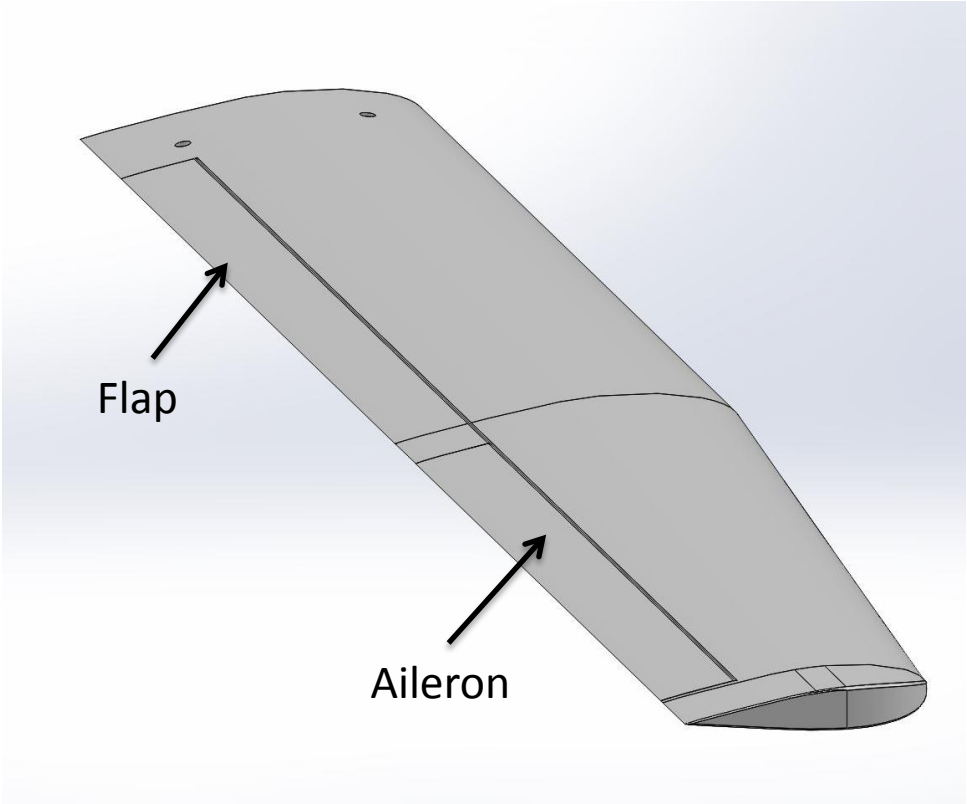
California Space Grant
CONSORTIUM

Project Objectives

- Build small UAS platform to allow for experimentation in active control of segmented control surface (SCS) wings
- Utilize compact fiber optic strain sensing (cFOSS) system to measure in-flight structural response
- Develop models to predict aerodynamic loading and structural response
- Control in-flight wing deformations using real-time cFOSS data

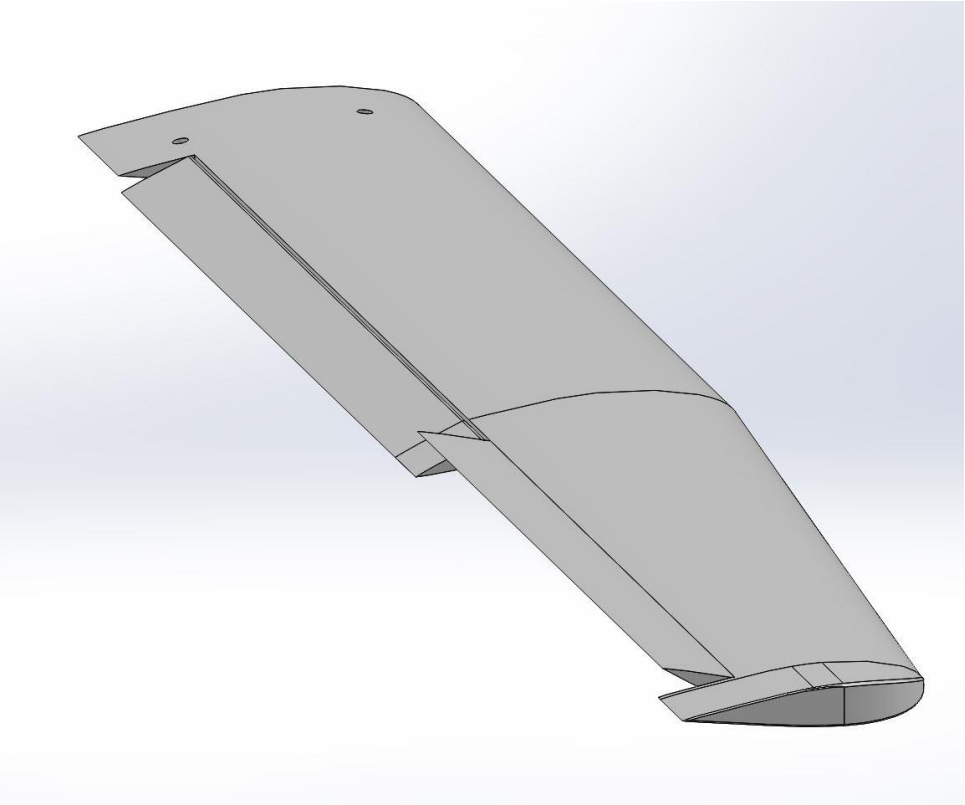
Segmented Control Surfaces

- Current wing control surface configurations often produce unnecessary structural and aerodynamic loads



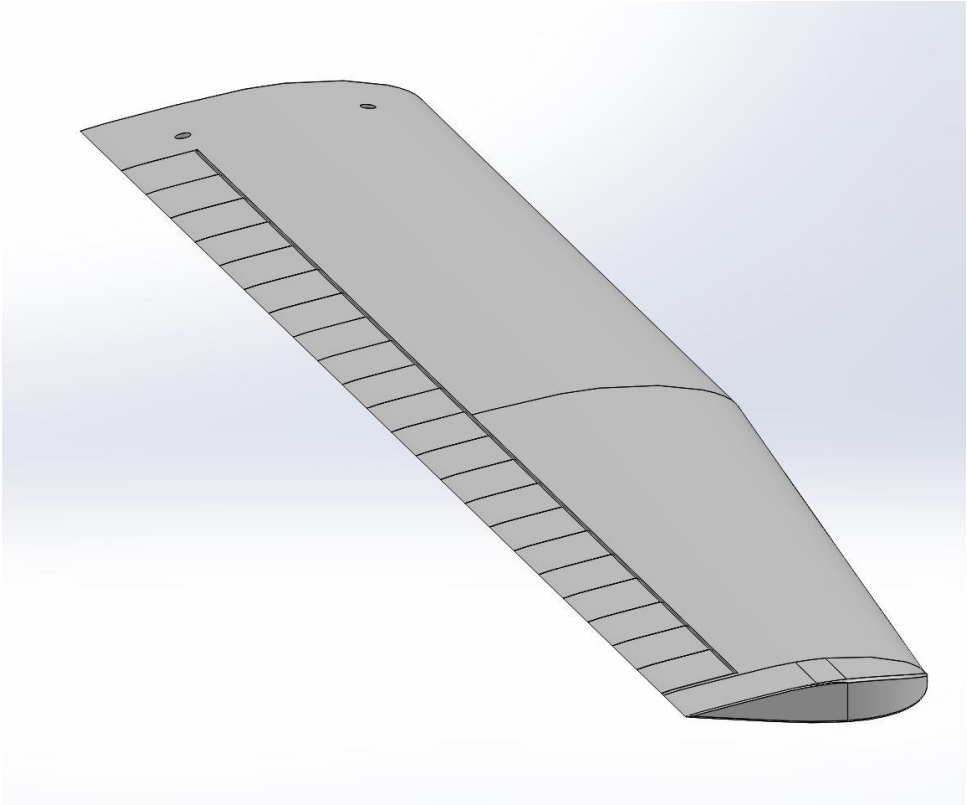
Segmented Control Surfaces

- Current wing control surface configurations often produce unnecessary structural and aerodynamic loads



Segmented Control Surfaces

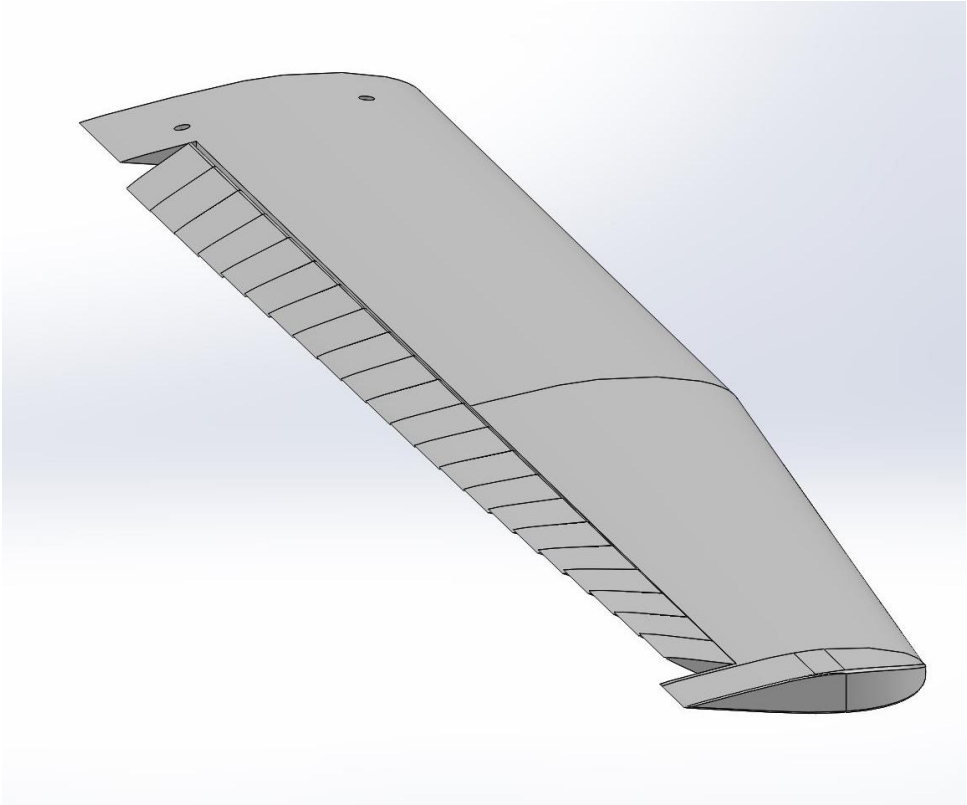
- Current wing control surface configurations often produce unnecessary structural and aerodynamic loads
- SCS allow for higher resolution of aircraft control input
- SCS can be optimized over the flight envelope
- Key step to implementation of conformal control surfaces/ flexible wing concepts



California Space Grant CONSORTIUM

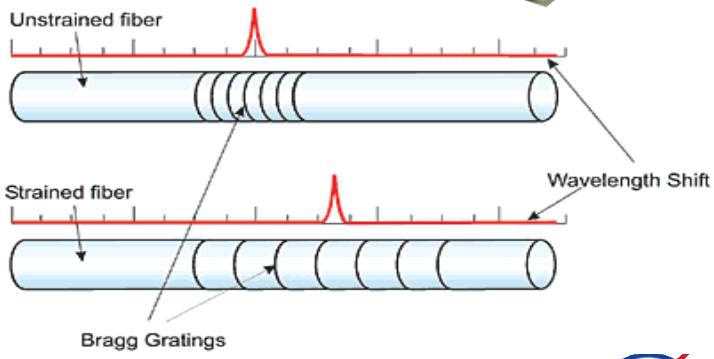
Segmented Control Surfaces

- Current wing control surface configurations often produce unnecessary structural and aerodynamic loads
- SCS allow for higher resolution of aircraft control input
- SCS can be optimized over the flight envelope
- Key step to implementation of conformal control surfaces/ flexible wing concepts



cFOSS System

- cFOSS system utilizes glass optical fibers as strain sensors
- Fiber Bragg gratings (FBG) distributed along fiber
- Laser interrogates fibers with incident light
- Straining fiber modifies FBG spacing and hence reflected wavelength
- Capable of ~4000 strain measurements at ~50Hz



California Space Grant CONSORTIUM

Overview

- Introduction
  - Aeronautics Academy Team
  - Objectives
  - Technologies
- System Description
  - Aircraft
  - Fiber Optic Sensor System
  - Segmented Control Surfaces
- Testing
  - Analytical Modeling
  - Flight Test Preparations
  - Flight Tests
- Results

California Space Grant CONSORTIUM

Aircraft (APV-3)

- Span: 12.33 ft
- Dihedral: 2.5˚along hinge line
- Structure: Monocoque composite
- Original control surfaces: Flap and aileron on each wing, split elevator, rudder
- Weight (without cFOSS system): ~35lbs
- Weight (with cFOSS system): ~45lbs
- Max gross takeoff weight: 55lbs
- Fully autonomous capabilities (Piccolo II)

California Space Grant CONSORTIUM

Fiber Optic Strain Sensors

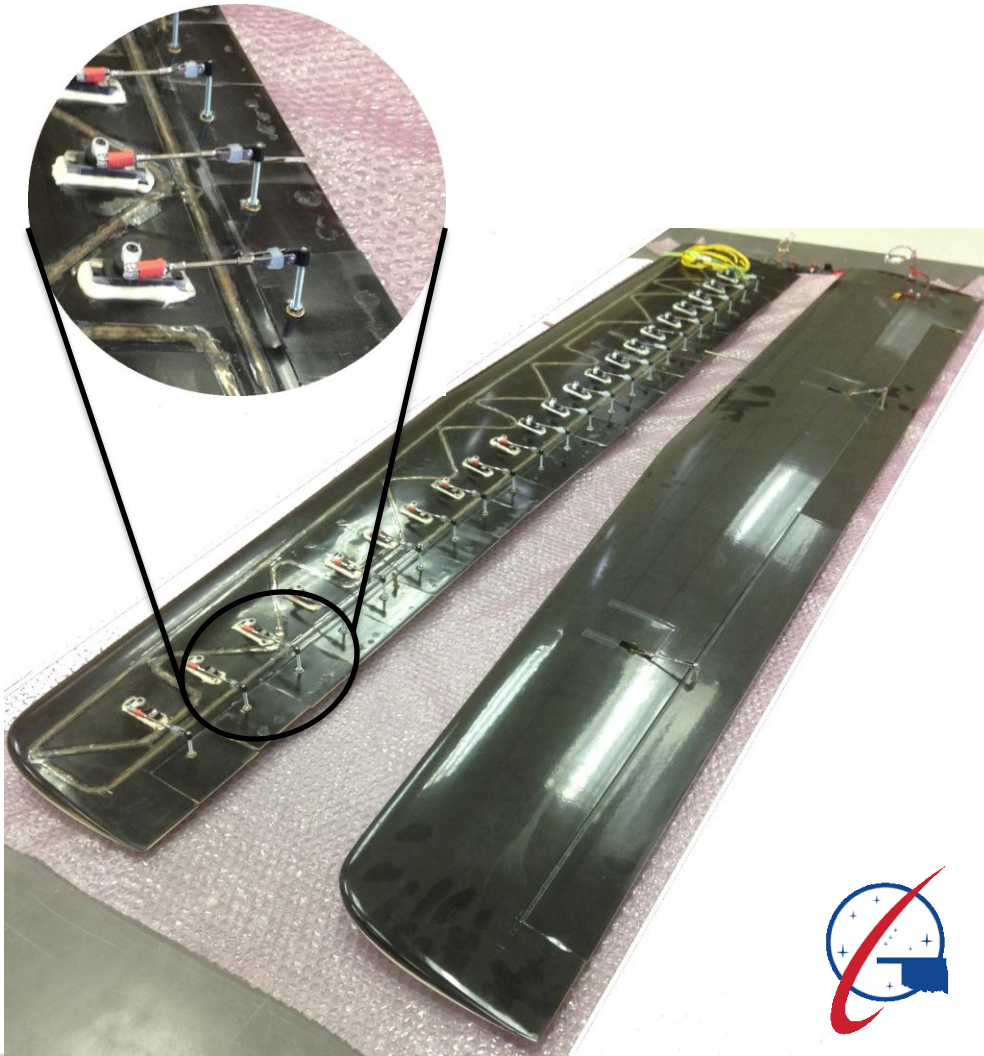
- Continuous grated fiber with strain data measured every 0.5”
- 86ft of fiber provides over 2000 real-time strain measurements
- Fiber rosettes allow for shape, displacement, twist and principle strain calculations

Fiber Optic Strain Sensors

California Space Grant CONSORTIUM

Segmented Control Surfaces

- Wings modified to include 22 independent control surface segments/servos per wing
- Servo uniformly spaced to produce 3” SCS from existing control surfaces



California Space Grant CONSORTIUM

Complete System

California Space Grant
CONSORTIUM

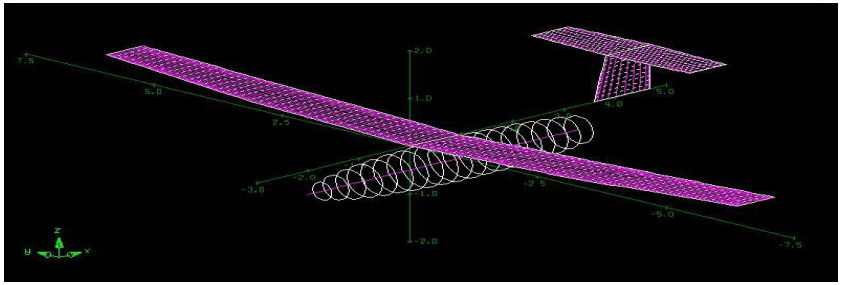
Overview

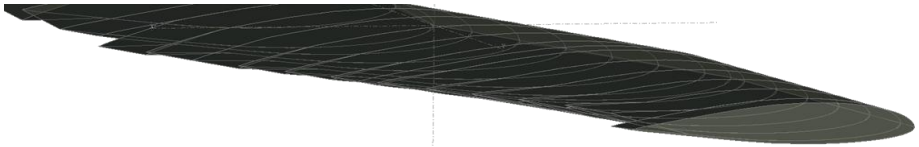
- Introduction
  - Aeronautics Academy Team
  - Objectives
  - Technologies
- System Description
  - Aircraft
  - Fiber Optic Sensor System
  - Segmented Control Surfaces
- Testing
  - Analytical Modeling
  - Flight Test Preparations
  - Flight Tests
- Results

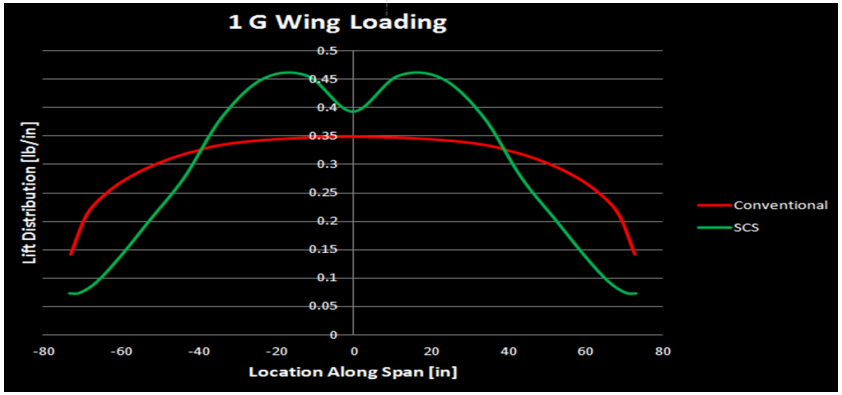
California Space Grant CONSORTIUM

Aerodynamic Analysis

- Utilized Athena Vortex Lattice (AVL) and XFLR5 programs
- Analytical model prepared for predicting aerodynamic loading of conventional and SCS configurations
- Aides in optimization of SCS configuration at various flight conditions



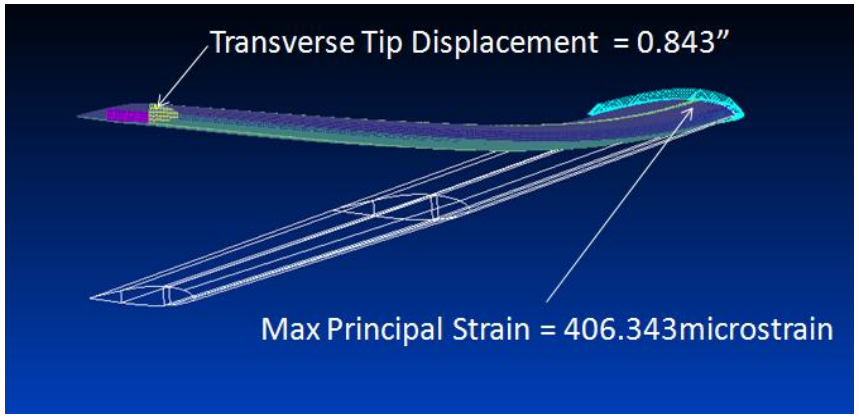




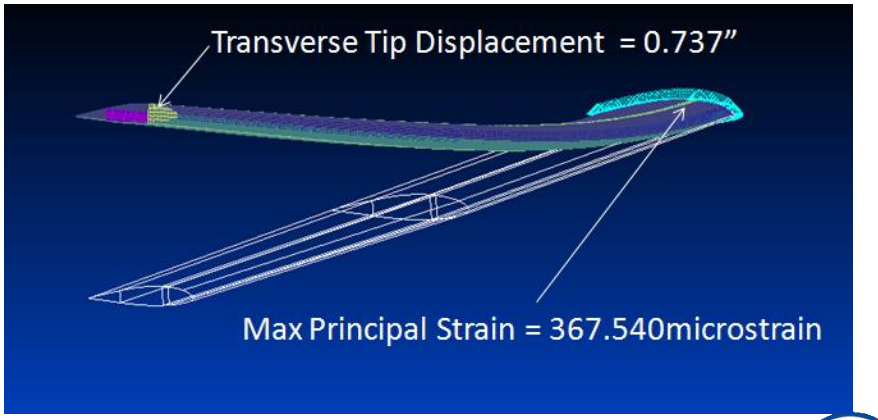
California Space Grant CONSORTIUM

Structural Analysis

- Developed 32,000 element single wing model in FEMAP
- Wing loaded along quarter chord with load distributions predicted by AVL (40 nodes along span)
- Model solved with NX Nastran yielding strain and displacement predictions
- Used to study effects of SCS configuration on displacement and strain



Conventional Control Surface

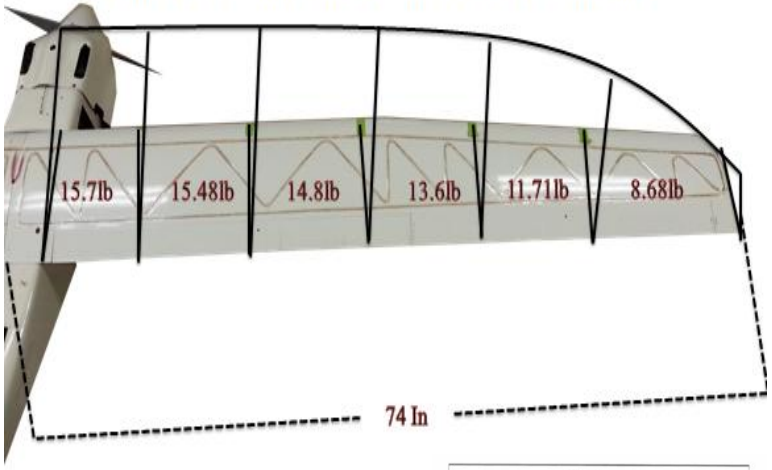


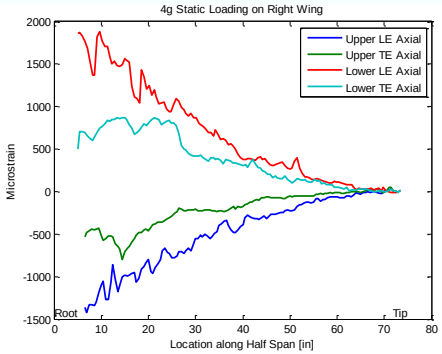
Segmented Control Surface

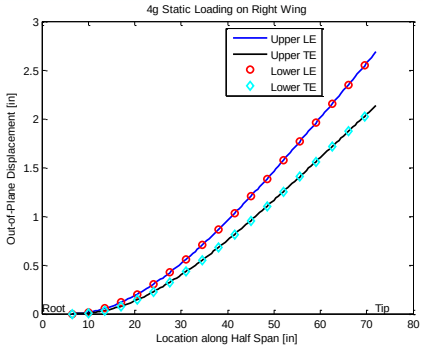
California Space Grant CONSORTIUM

Pre-Flight Requirements

- 4g static loading distribution on right wing







Flight Request

FLIGHT NUMBER(S): APV-3 Project	DATE OF REQUEST: 7/23/2013
AIRCRAFT: APV-3	DATE(S) OF FLIGHT(S): 7/30/13 (and thereafter, as configured)

FLIGHT CREW:
Flight Test Director: Mike Marston
Crew Chief: Hovig Yarslian
Lead Operations Engineer: Benjamin Martins
Scribe: Nathan Suppanade
Pilot: Glen Bever
Safety Director: Mike Marston
Observers: Benjamin Martins, Corbin Graham

PURPOSE OF FLIGHT(S):

Performs steady level flight patterns while collecting data using the Fiber Optic Strain Sensing (FOSS) technology. The FOSS system will be stored in the canoe of the aircraft and will collect data in flight.

Will be testing newly instrumented wings that have been modified with 22 servos per wing. The servos are non functioning and are only used for ballast currently.

The wings are also modified with the fiber optic sensors to measure strain in flight. Data collection with the newly instrumented wings will be collected and used for future use of the segmented trailing edge concept.

APV-3 is equipped with a CCT Piccolo Plus autopilot to record aircraft state data, however, autonomous aircraft control is possible with this configuration.

Flights will also include training activities for RC Pilot (Safety Pilot) and GCO (Pilot-Operator) proficiency as required.

RISK ASSESSMENT (Check one): ☐ HIGH ☐ MEDIUM ☒ LOW

ORIGINATOR'S NAME AND ORG: Michael L Marston, OE	SIGNATURE: MMcHall Remotec	DATE: 7/25/13
DIRECTOR, RESEARCH & ENGINEERING (Code R): Glen Bever	SIGNATURE:	DATE:
DIRECTOR, FLIGHT OPERATIONS (Code D): Jim Smolka	SIGNATURE:	DATE:
Chief Pilot (Code OF): Nils Larson	SIGNATURE:	DATE:
MISSION DIRECTOR (Code P): John Del Frate	SIGNATURE:	DATE:
DIRECTOR, SAFETY AND MISSION ASSURANCE (Code S): Jonathan Brown	SIGNATURE:	DATE:
DIRECTOR, MISSION INFORMATION & TEST SYSTEMS (Code M): Sean McMorrow	SIGNATURE:	DATE:
OTHER (Name and Organization):	SIGNATURE:	DATE:
OTHER (Name and Organization):	SIGNATURE:	DATE:
DFRC CHIEF ENGINEER (Code X): Allison Bowers	SIGNATURE:	DATE:

D-000, 126-7
Rev. 2, 2/2/2010
Only the current revision will be accepted.

California Space Grant CONSORTIUM

Complete Systems Test

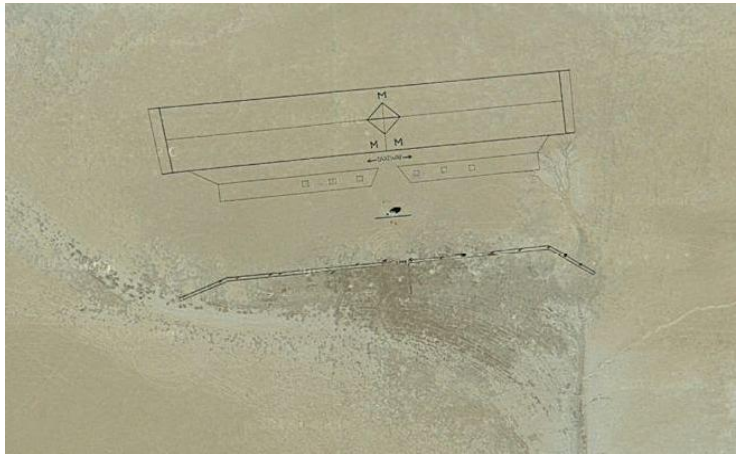
California Space Grant
CONSORTIUM

Complete Systems Test Video

California Space Grant
CONSORTIUM

Test Flights

- Test flights conducted at Dryden Flight Research Center small UAS work area
- Same Flight Patterns flown with (mimicked) conventional and segmented control surface configurations
- Circuits Flown
  - Steady Level Flight
  - Pitch Doublets
  - Roll Doublets
  - High g Steady Turn



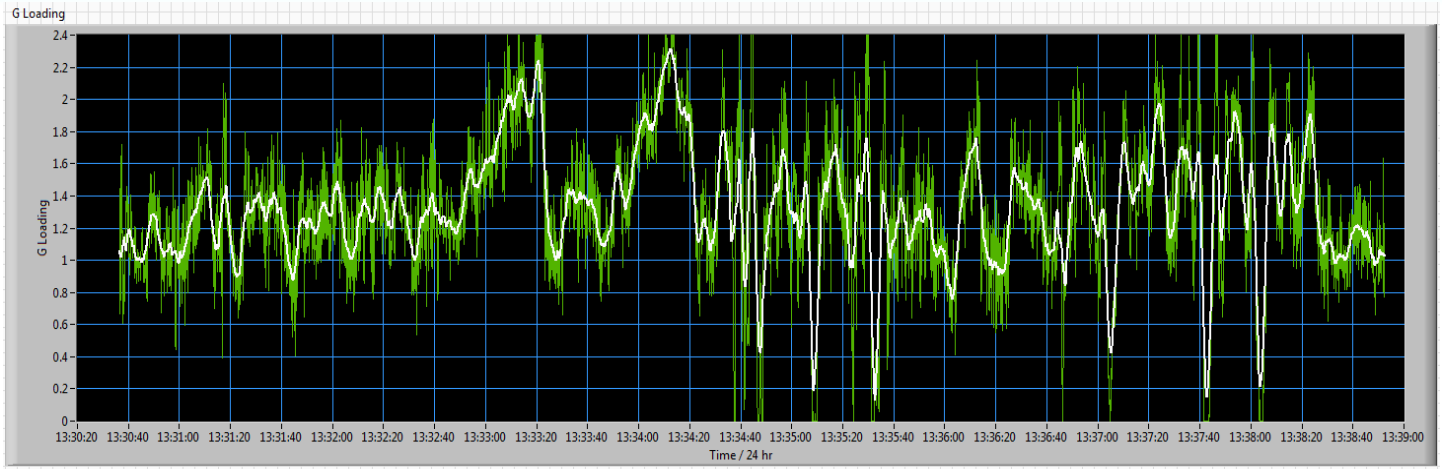
California Space Grant CONSORTIUM

Overview

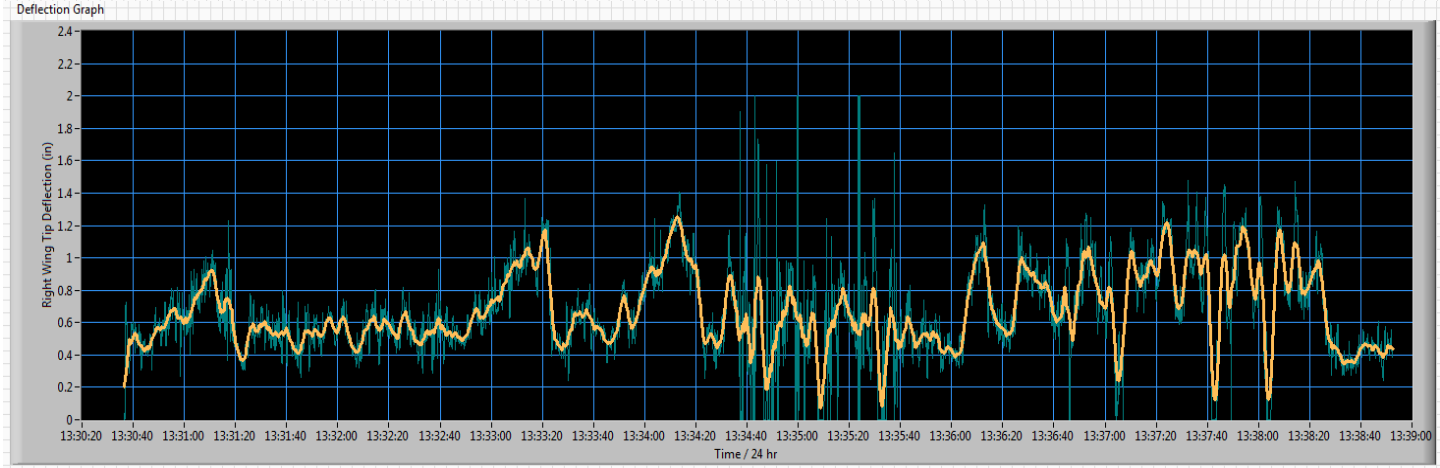
- Introduction
  - Aeronautics Academy Team
  - Objectives
  - Technologies
- System Description
  - Aircraft
  - Fiber Optic Sensor System
  - Segmented Control Surfaces
- Testing
  - Analytical Modeling
  - Flight Test Preparations
  - Flight Tests
- Results

Flight Results-Time History

Filtered Acceleration vs. Time



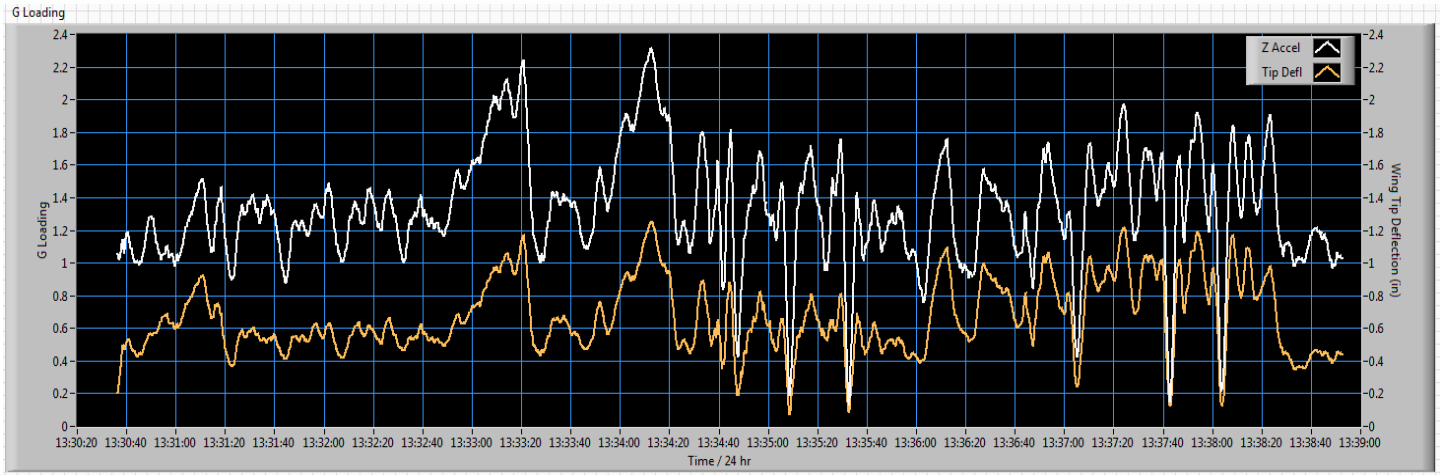
Filtered Wing Tip Deflection vs. Time



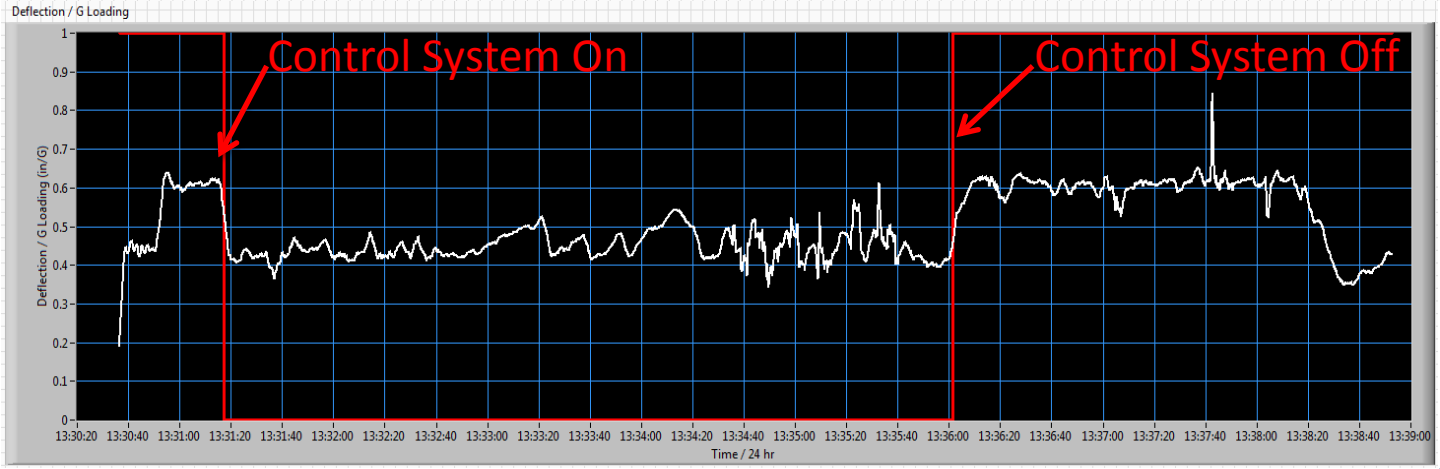
California Space Grant CONSORTIUM

Flight Results-Time History

Filtered Acceleration and Wing Tip Deflection vs. Time



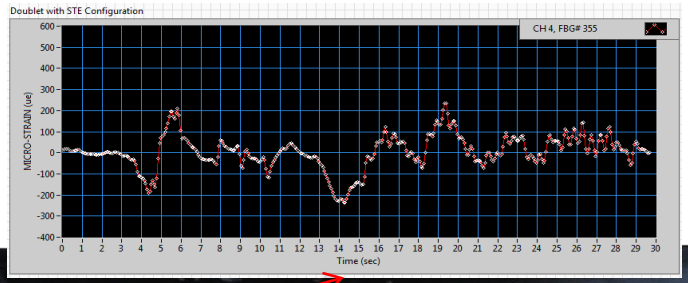
Normalized Wing Tip Deflection vs. Time

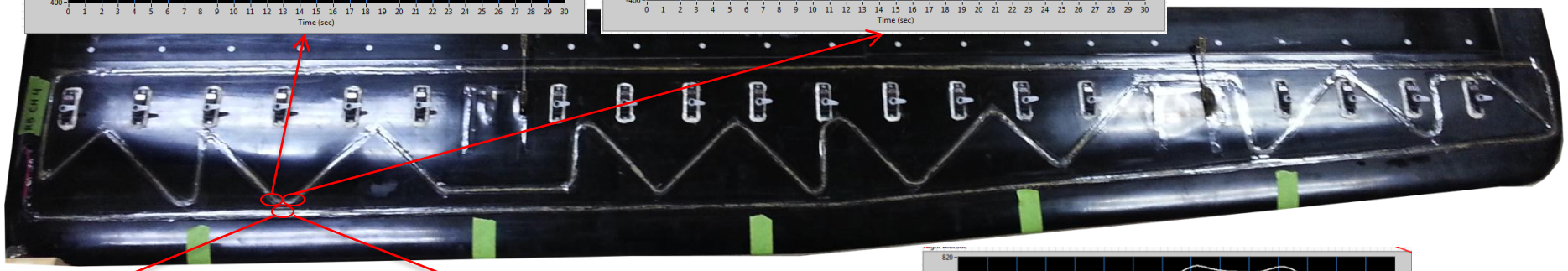


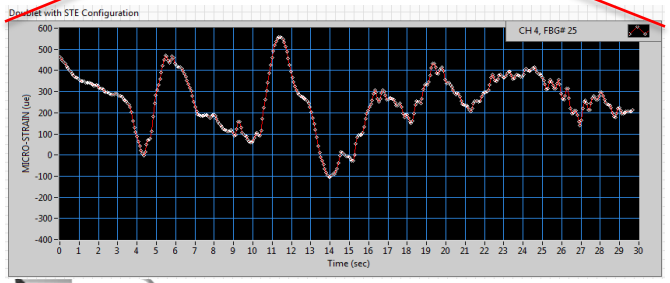
California Space Grant CONSORTIUM

Flight Results-Time History

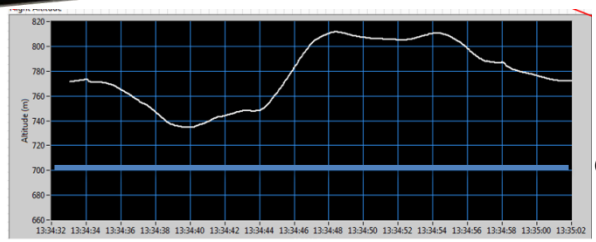
- Pitch doublet (~30 sec) strain data for 3 sensors (25, 345, 355)





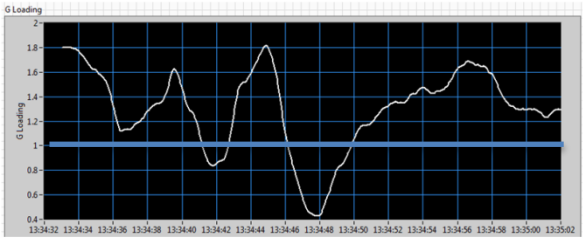


Altitude



Ground Level

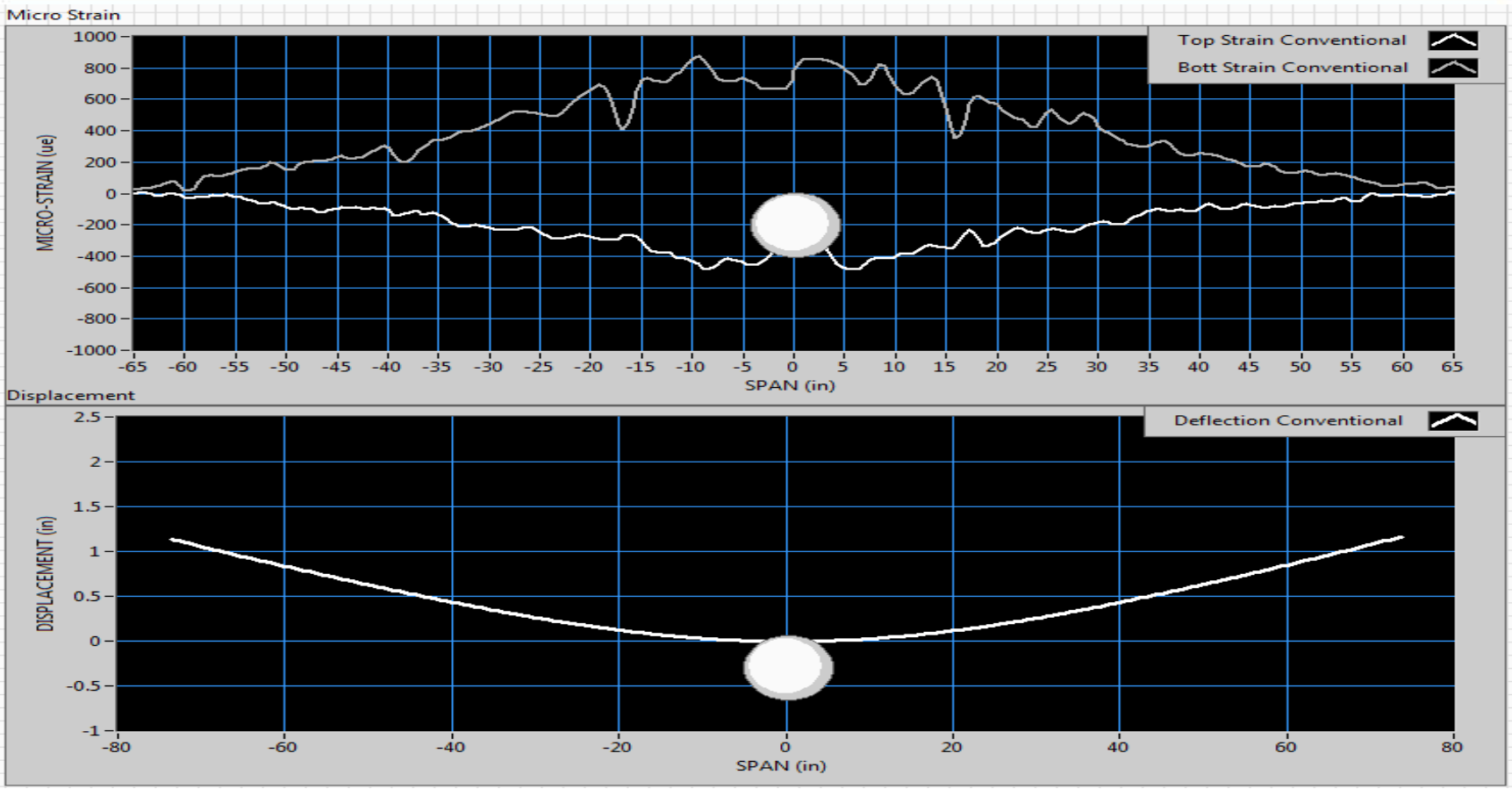
Acceleration



1g

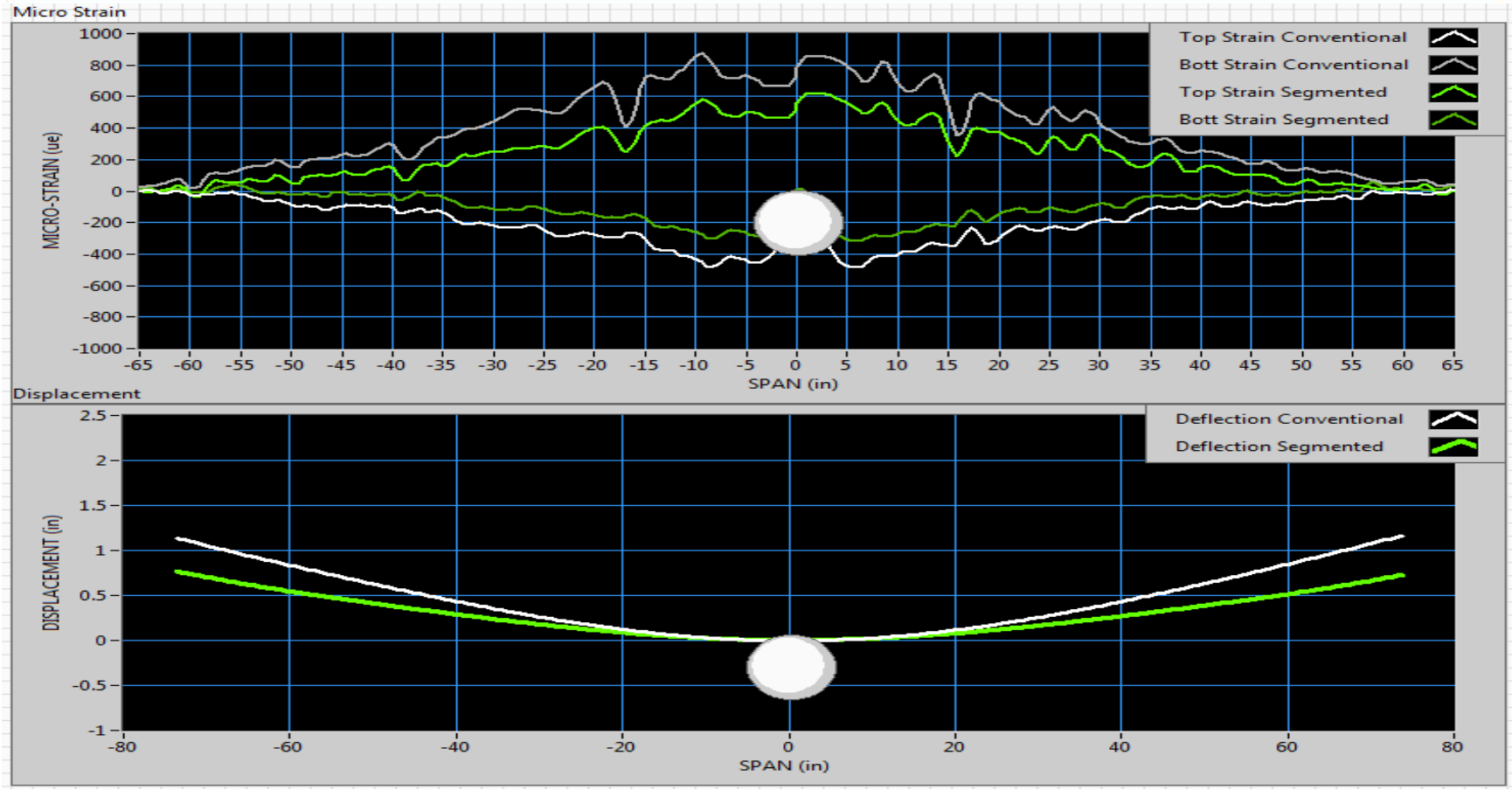
California Space Grant CONSORTIUM

Flight Results-Conventional



California Space Grant
CONSORTIUM

Flight Results-SCS



California Space Grant
CONSORTIUM

Future Objectives

- Design and build high aspect ratio wings with SCS and FBG fibers to allow for wider range of wing displacements and SCS control

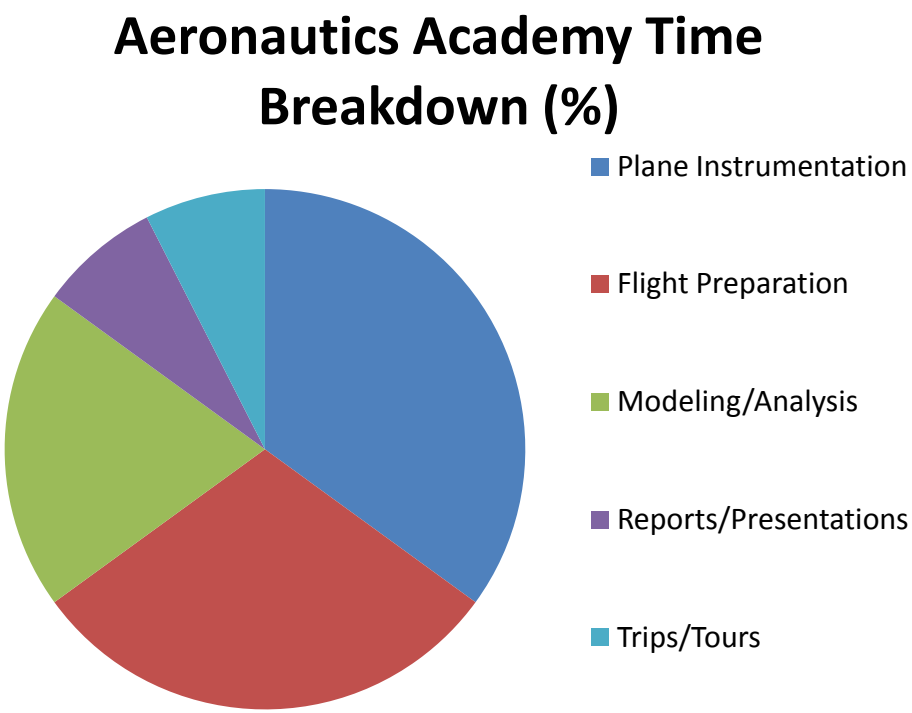
- Design advanced control architecture for controlling/monitoring of dynamic events
  - Gust Alleviation
  - Flutter Suppression
  - Structural Health Monitoring

- Transition to conformal trailing edge materials

Personal Reflection

- Aeronautics Academy was the experience of a lifetime:
  - Jump started my PhD research
  - Created valuable personal and profession contacts
  - One of a kind practical flight research experience

- California Space Grant Consortium:
  - Gave me research opportunities as an undergraduate with no experience
  - Influenced my decision to go to graduate school
  - Provided support so that I could pursue my research interest both through the Academy and at UCSD



California Space Grant CONSORTIUM

Acknowledgements

I would like to thank my mentors,

- Dr. John Kosmatka, University of California, San Diego
- Dr. Lance Richards, NASA DFRC/AERO Institute

And Teammates,

- Corbin Graham, The University of Oklahoma
- Nathan Suppanade, California State University, Los Angeles

As well as numerous people at NASA Dryden who provided advice, guidance and support, including:

- Robert "Red" Jensen
- Francisco Pena
- Allen Parker
- Dr. Patrick Chan
- Gary Williams
- Dr. Oscar Murillo
- Anthony Piazza
- Michael Marston

California Space Grant CONSORTIUM

Support

Funding for this project was provided by:

- NASA Aeronautics Academy, Dryden Flight Research Center
- California Space Grant Consortium
- Oklahoma Space Grant Consortium

California Space Grant
CONSORTIUM

Questions?

California Space Grant
CONSORTIUM