Structural Implementations of Leading-Edge Noise Reduction Devices

Travis Turner

Airframe Noise Technical Challenge

AATT Project

Acoustics Technical Working Group Meeting

April 21-22, 2015

Acknowledgements

Aeroacoustics
- David Lockard
- Mehdi Khorrami
- Craig Streett
- John Lin

Prototype Development
- George Hilton
- Larry Becker, NG
- Ron Penner, STC
- Rick Thomas, STC

NASA AATT Project

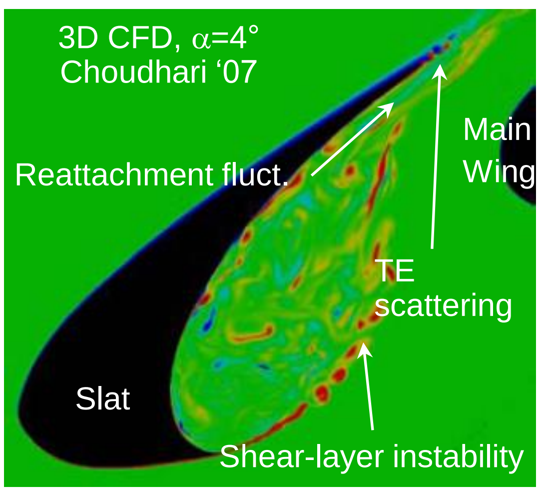
Materials & Structures
- Travis Turner
- Jim Moore
- Mia Siochi
- Jin Ho Kang, NIA
- Reggie Kidd, AMA
- Dave Long, AMA
- Darren Hartl, TAMU
- Will Scholten, TAMU

SMA Components
- Joe Kain, JM
- Carlos Pimentel, JM

Airframe Noise Mitigation Concepts

Airframe Noise Sources

Wing Leading Edge Cross Section



Background

- Airframe noise comparable to engine noise during approach
- Slats & flaps are major contributors

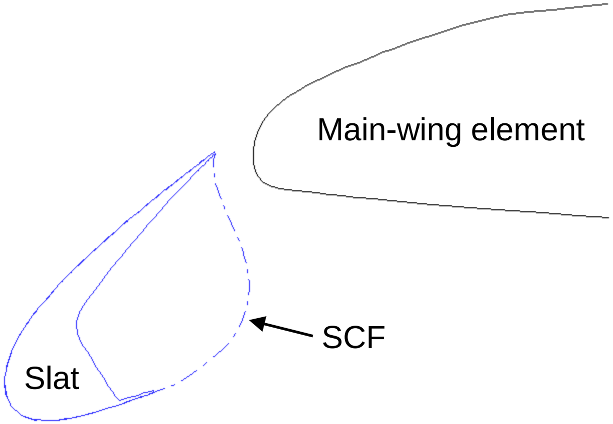
Characteristics

- Multi-element airfoil increases lift
- Unsteady flow creates noise

Challenge: Reduce airframe noise w/o aero compromise (cruise or landing)

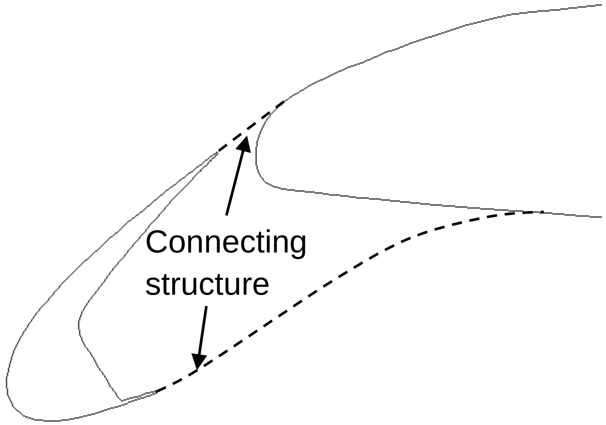
Notional Solutions for Slat Noise

Slat-Cove Filler



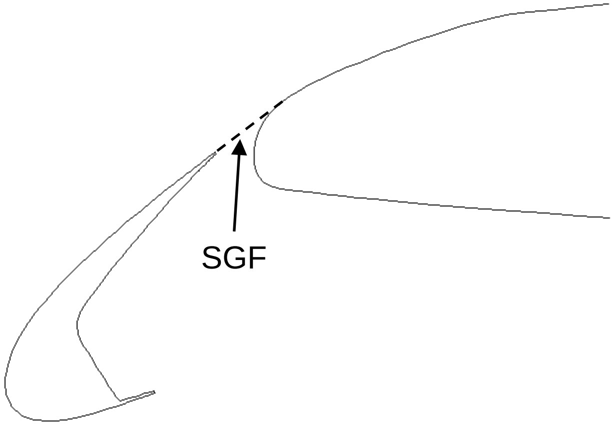
- Moderate noise reduction (3-4 dB)
- Excellent high-lift
- Low weight & complexity

Drooped Leading Edge



- Excellent noise reduction (>8 dB)
- Compromised high-lift
- High weight & complexity

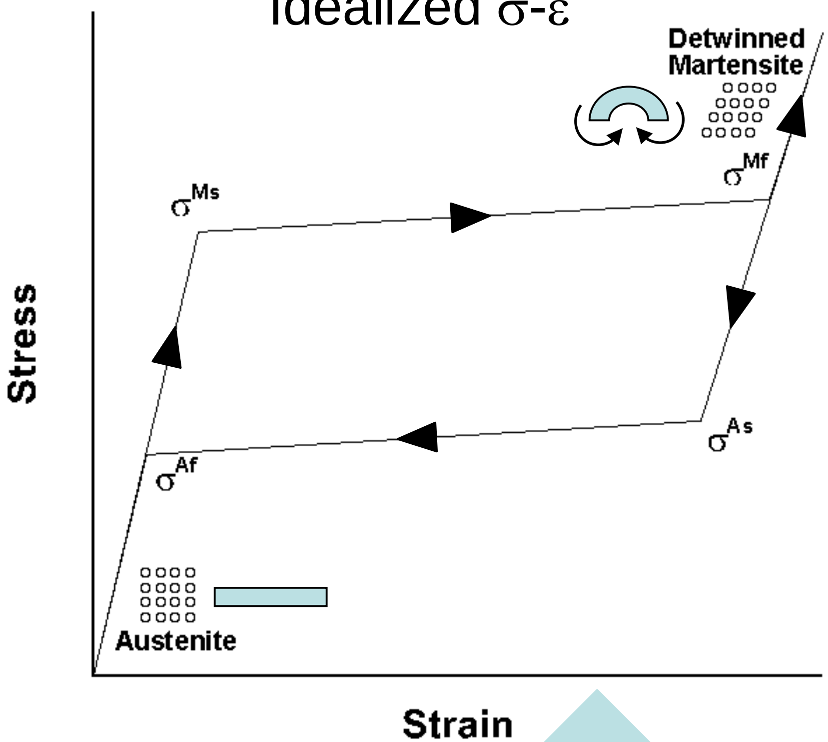
Slat-Gap Filler



- Excellent noise reduction (>8 dB)
- Excellent high-lift
- Mod. weight/complexity

Superelastic SMA Material

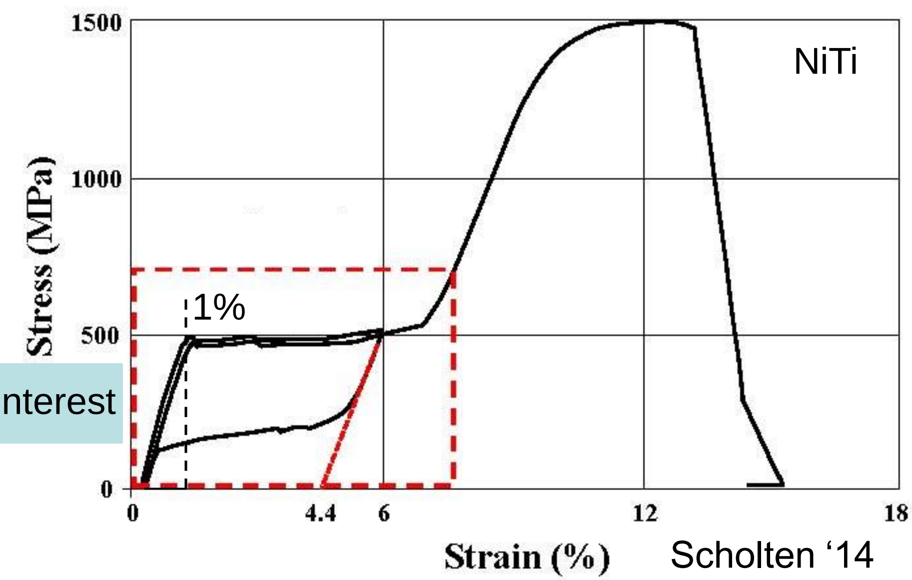
Idealized σ-ε



- Exhibits reversible, stress-induced transformation
- Enabling for large deform. implied by configuration change
- ~1% linear range typical

σ-ε Region of Interest

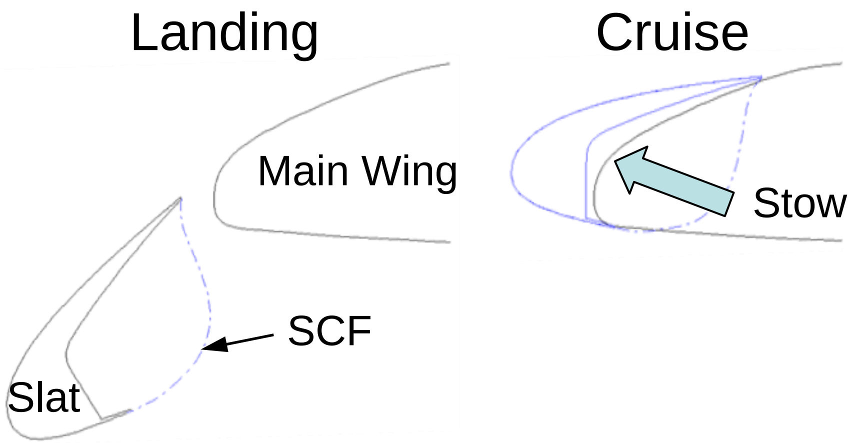
Measured σ-ε

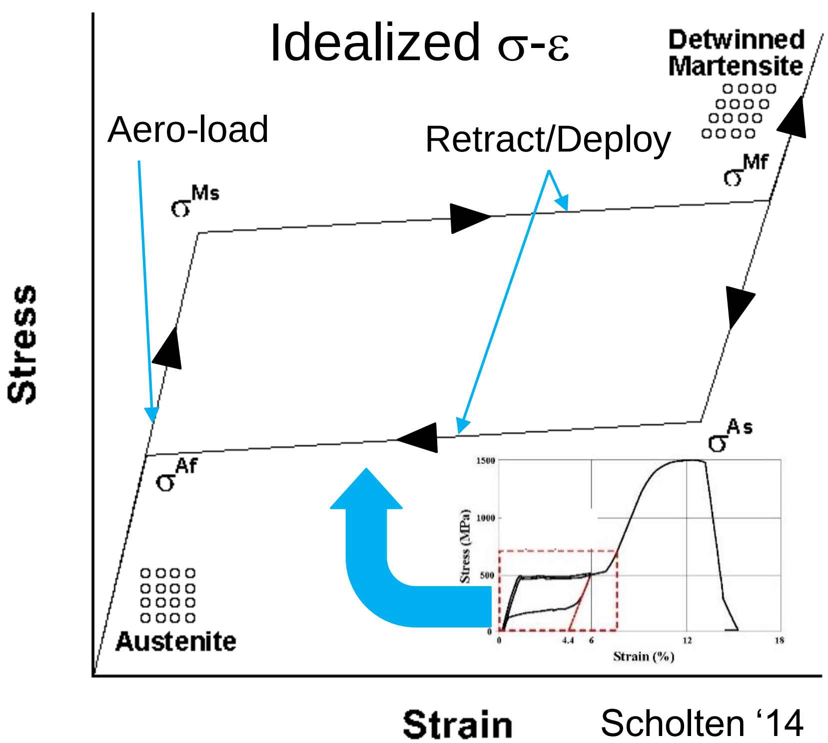


Scholten '14

Superelastic Slat-Cove Filler (SCF)

Superelastic SMA SCF Concept





Objective

Fill slat "cove" w/ reconfig. structure to guide gap flow & reduce noise

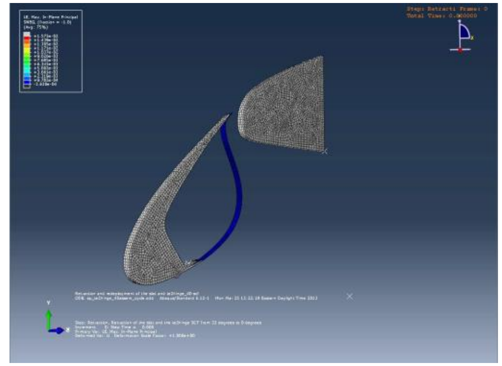
Requirements

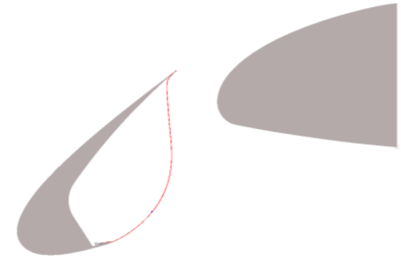
- Match P_T profile
- High def. (>2%)
- Simple & low wt.
- Sustain aero load
- Deploy/stow w/ slat
- Failsafe

Approach

- Employ superelastic SMA
- Heat treat to deployed shape
- Hinge at cusp
- Distributed aero-load avoids σ^{Ms}
- SCF-Main wing contact causes stowage
  - Conc. load, locally exceeds σ^{Ms}
  - SCF deforms as needed to stow
- Autonomous redeployment

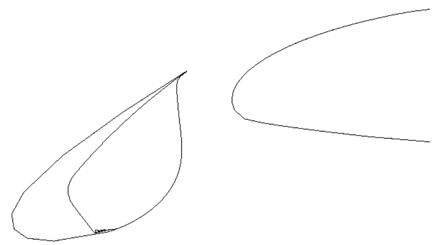
Superelastic SMA SCF Status





Model Results/Trends

- Approaching monolithic design
- Variable thickness advantageous
- Actuator authority/contact an issue



Refinements – reduce actuator req.

- Hinge actuator
- Spanwise discrete topology → continuous
- Variable thickness via topology opt.

Extension – raise TRL

- 3D effects – sweep, taper
  - Moving to CRM geometry
  - CRM SCF design underway
- Fluid-structure interaction
  - Abaqus/CFD not a good option
  - Collaboration with ATA, FUN3D-Abaqus via Co-Simulation Engine

Shape Memory Polymer Composite SCF

SMPC SCF Status

Previous Results/Trends

- Variable stiffness required
- Autonomous deployment possible
- Insufficient stiffness control & durability

Objectives

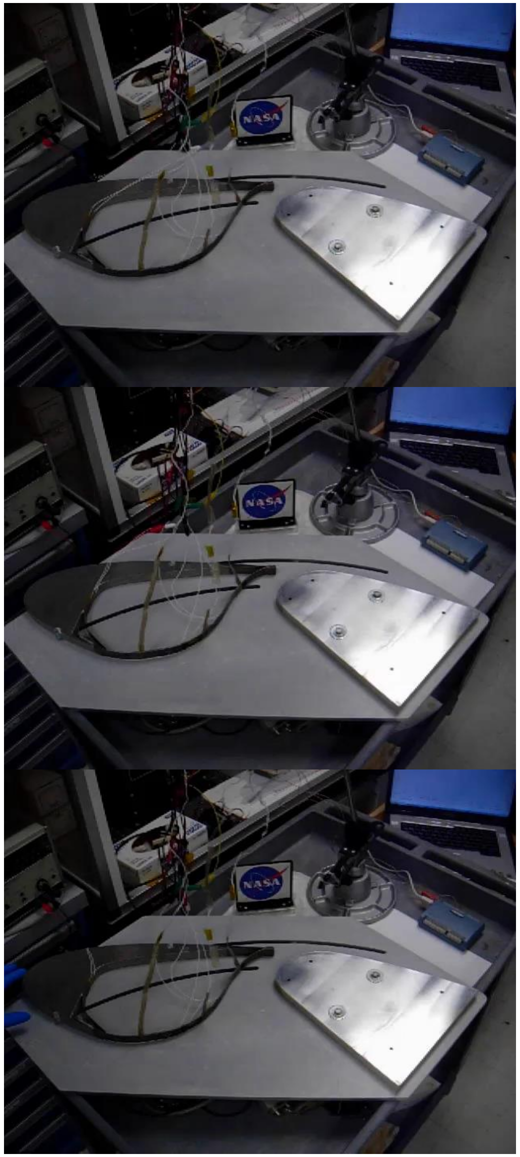
- Improve SMPC strength & durability
- Demonstrate deployable SMPC SCF

Approach

- Embed Kevlar fabric
- Explore surface vs. Joule heating

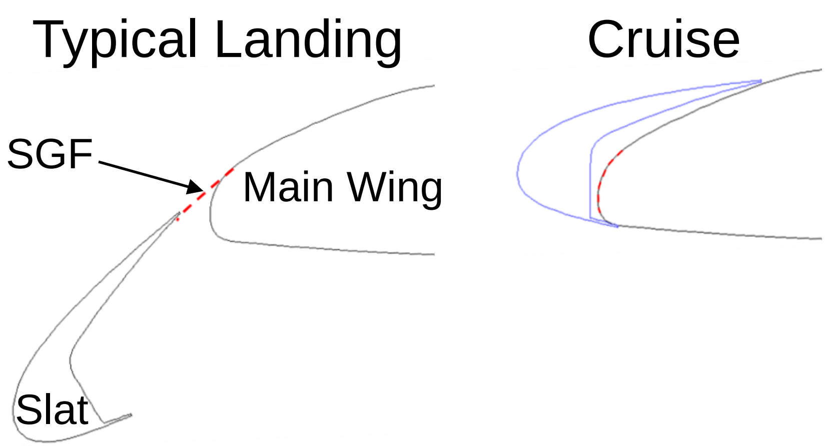
Results

- Demonstration achieved
- Still working stiffness control and durability



Superelastic Slat-Gap Filler (SGF)

Superelastic SMA Slat-Gap Filler (SGF)

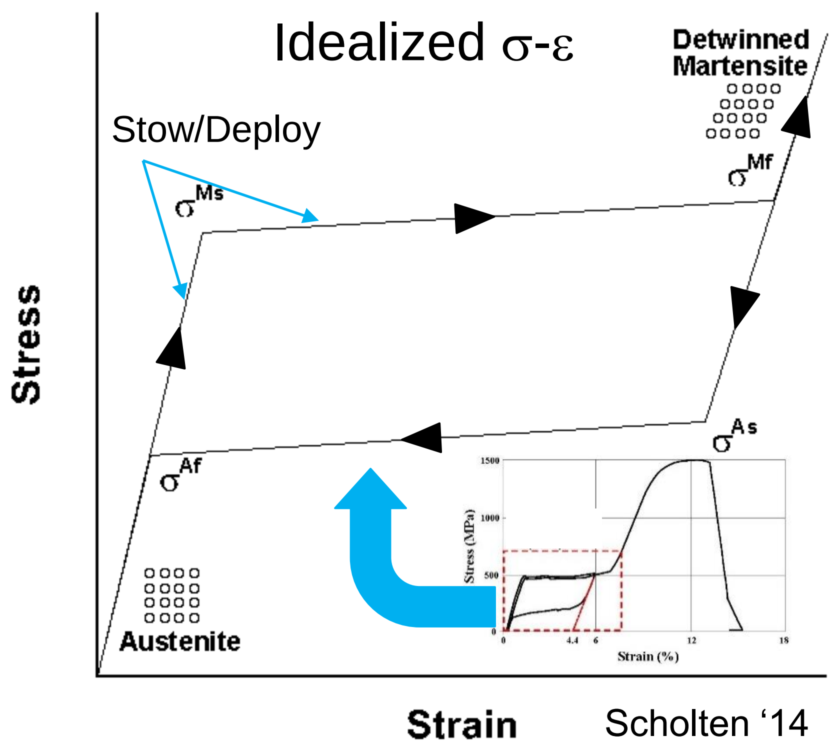


Objective

Block gap flow to ~eliminate noise, open gap on demand

Requirements

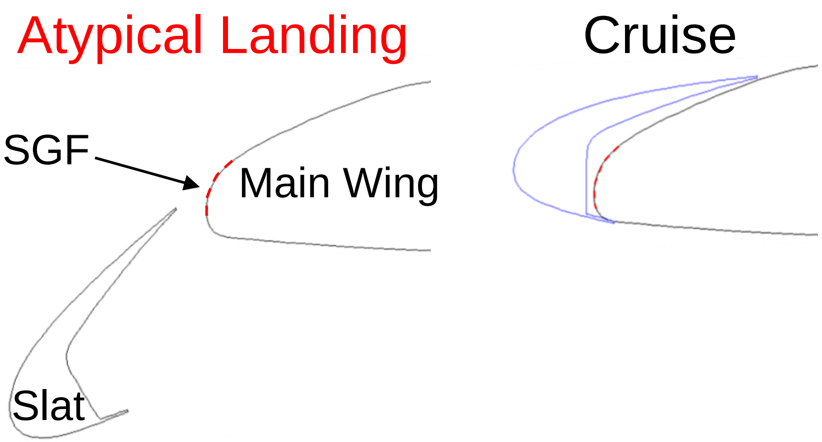
- Attached flow @ typical α, gap open at high α
- High def. (~1%)
- Sustain aero load
- Deploy/stow w/ slat
- Simple & low wt.
- Failsafe

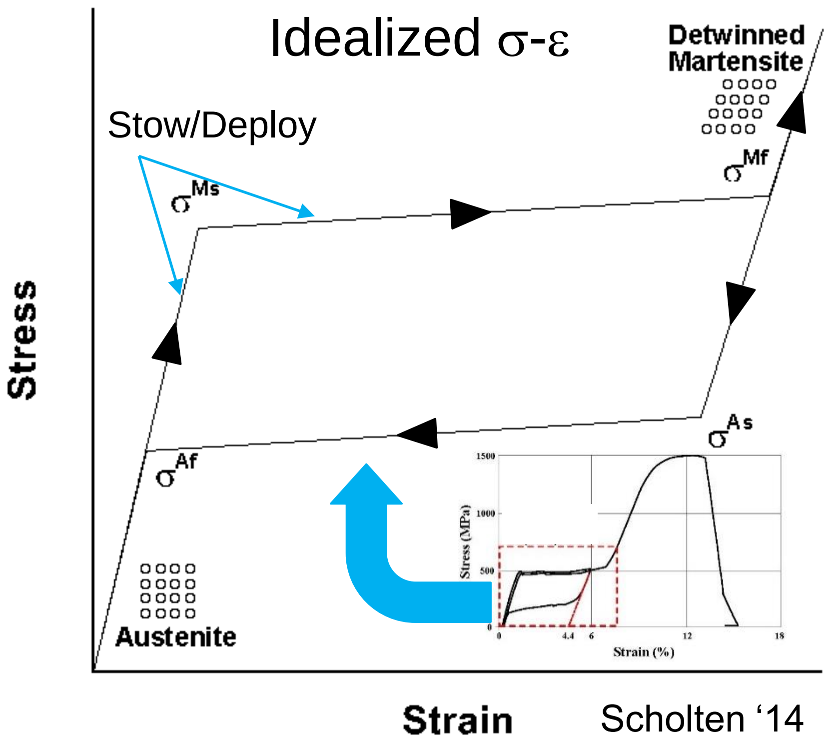


Approach

- Employ superelastic SMA
- Overlay stressed-skin on main wing
- Heat treat &/or bias to stowed shape

Superelastic SMA Slat-Gap Filler (SGF)





Objective

Block gap flow to ~eliminate noise, open gap on demand

Requirements

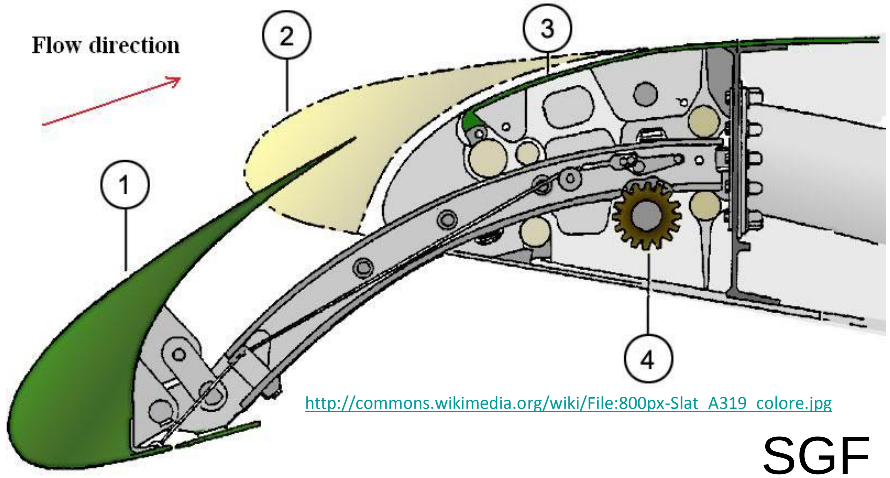
- Attached flow @ typical α, gap open at high α
- High def. (~1%)
- Sustain aero load
- Deploy/stow w/ slat
- Simple & low wt.
- Failsafe

Approach

- Employ superelastic SMA
- Overlay stressed-skin on main wing
- Heat treat &/or bias to stowed shape
- Gap opens when required @ high α

Superelastic SMA Slat-Gap Filler (SGF)

Typical Slat Mechanism

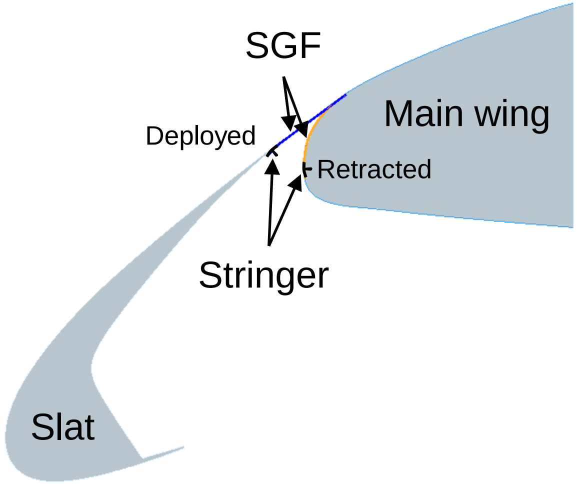


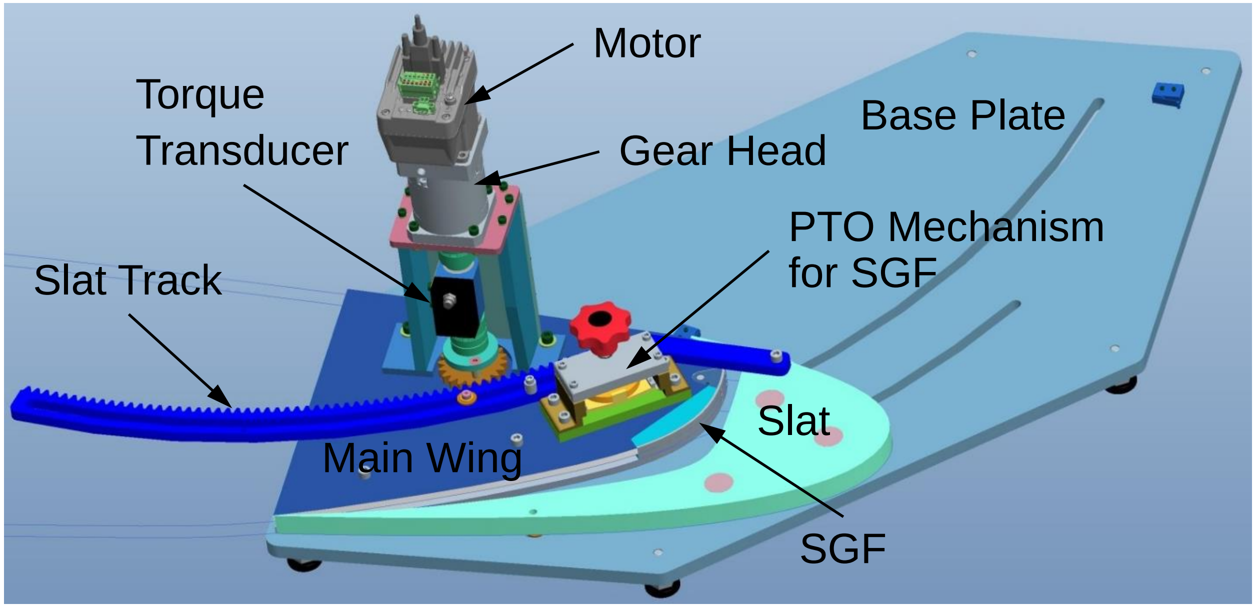
Approach (Contd.)

- Actuation motiv. by typ. mechanism
- SGF actuated by PTO on slat track
- Control force @ SGF tip – stringer
- Heat-treat options, stress-free deployed/retracted

SGF Mechanized Bench-Top Apparatus

SGF Schematic

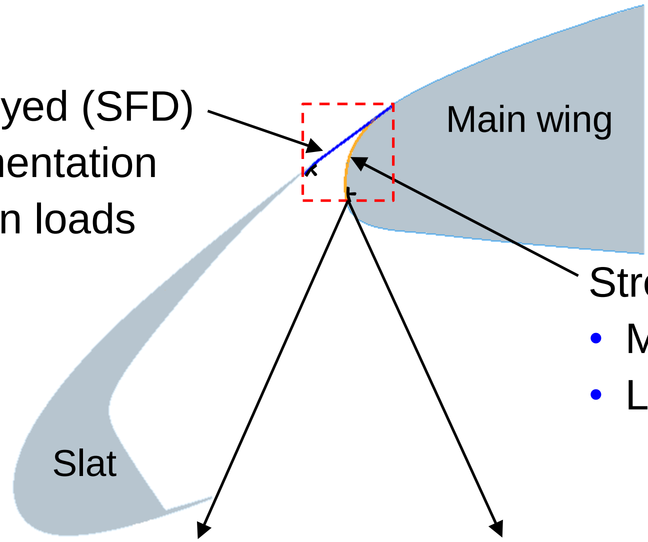




Stress-Free-Deployed (SFD) SGF

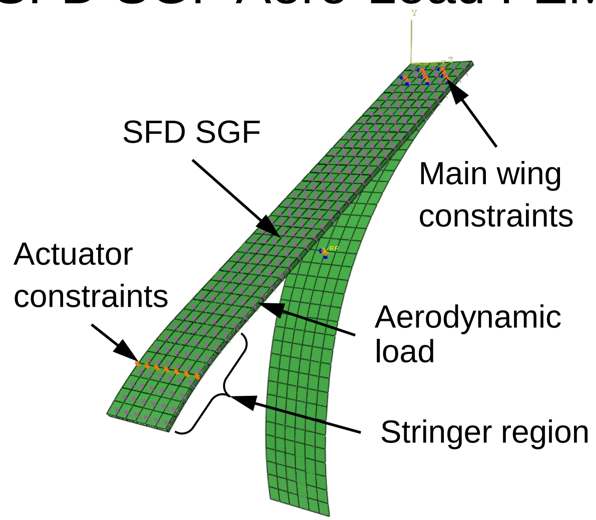
Computational Region of Interest

Stress-free deployed (SFD)
- Simpler implementation
- Higher actuation loads

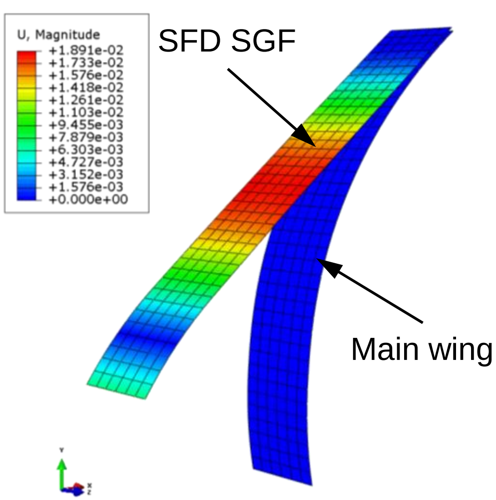


Stress-free retracted (SFR)
- More complex implementation
- Lower actuation loads

SFD SGF Aero-Load FEM

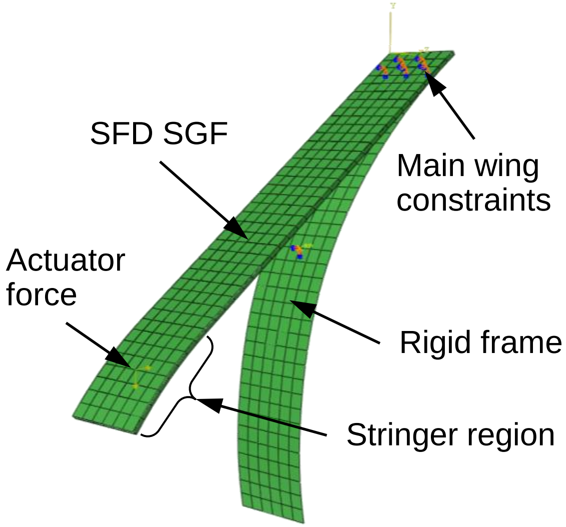


Aero-Load Displacement

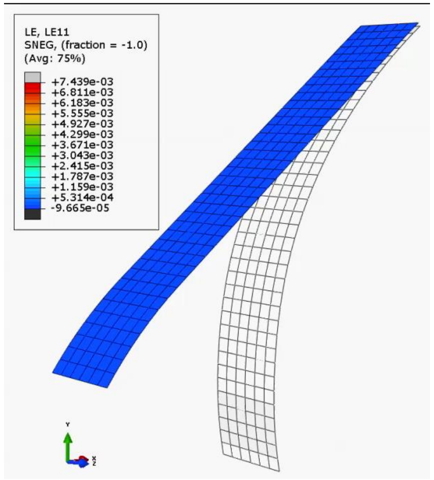


Stress-Free-Deployed (SFD) SGF

SFD SGF Retract FEM



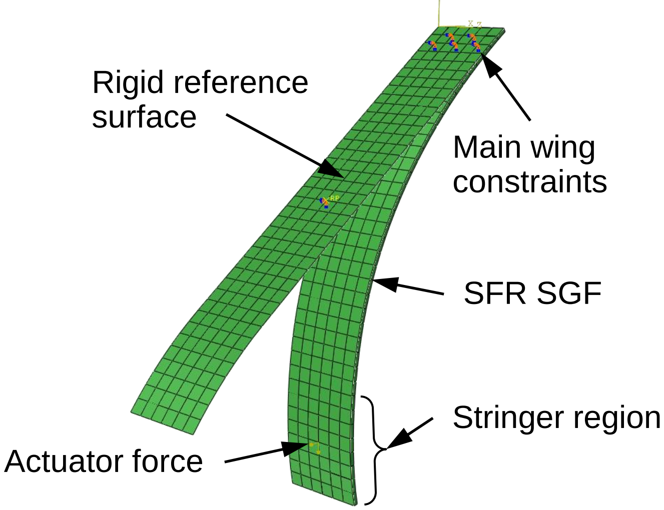
SFD SGF Retract Strain



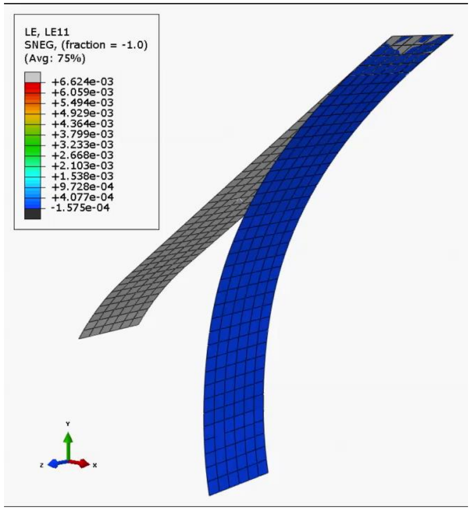
- ~10.7 lbf/in required to retract 0.040”-thick SFD SGF
- Max strain ~0.74%
- Reduce thickness to 0.020”, nominally min-gage
  - Actuator requirement for retraction → ~1.3 lbf
  - Aero-load max displacement → 0.033”
- Aero-load and restoring force combine indirectly
  - Increased actuator force and bias requirement
  - Fail-safety more difficult

Stress-Free-Retracted (SFR) SGF

SFR SGF Deploy FEM



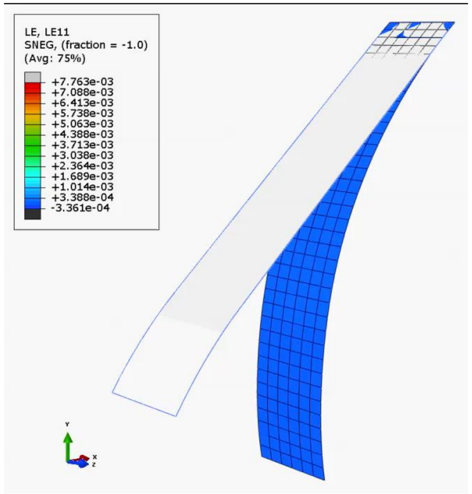
SFR SGF Deploy Strain



- ~10.7 lbf/in required to deploy 0.040”-thick SFR SGF
- Max strain ~0.66%
- Reduce thickness to 0.020”, nominally min-gage
  - ➢ Actuator requirement for deployment → ~1.3 lbf
- Aero-load and restoring force oppose one another
  - ➢ Reduced actuator force and bias requirement
  - ➢ Fail-safety less difficult

Stress-Free-Retracted (SFR) SGF

Unconstrained Shape & Strain

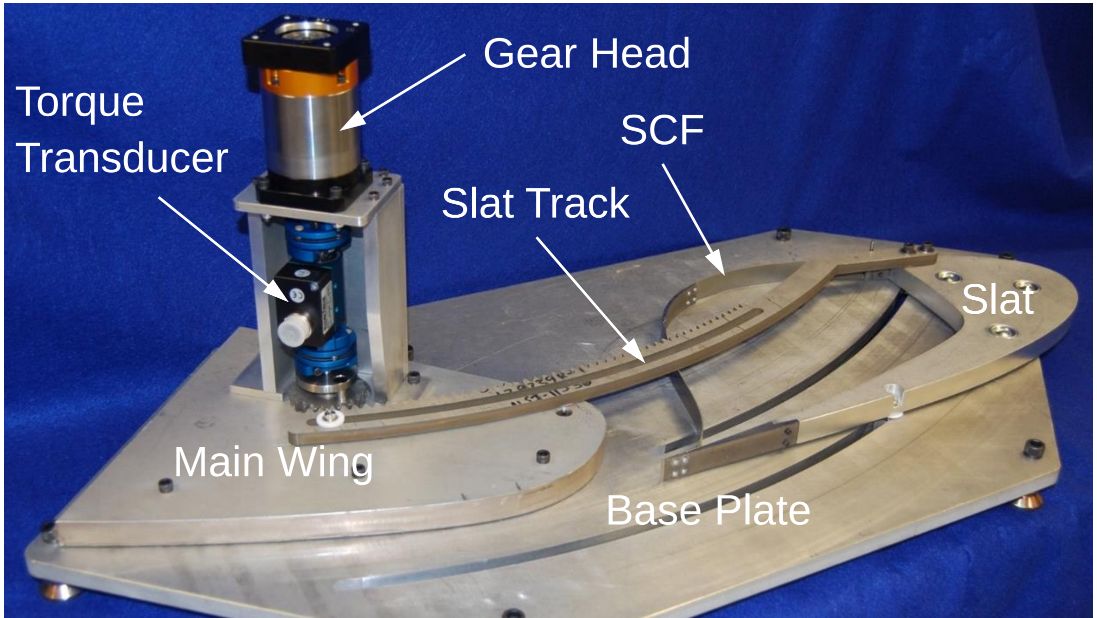


- Relax constraint on deployed shape
  - ~3.3 lbf/in required to deploy 0.040”-thick SFR SGF
  - Max strain ~0.78%
  - Deflected shape exceeds reference by ~0.2”
- Aero-load deflection of 0.040”-thick SGF negligible
- Unconstrained, 0.020”-thick SFR SGF requires ~0.4 lbf/in for deployment & aero-load deflection negligible

SCF & SGF Bench-Top Testing

SCF Mechanized Bench-Top Apparatus

Objective: Quantitatively explore parameter space & validate computational models



SCF Bench-Top Apparatus – SGF Similar

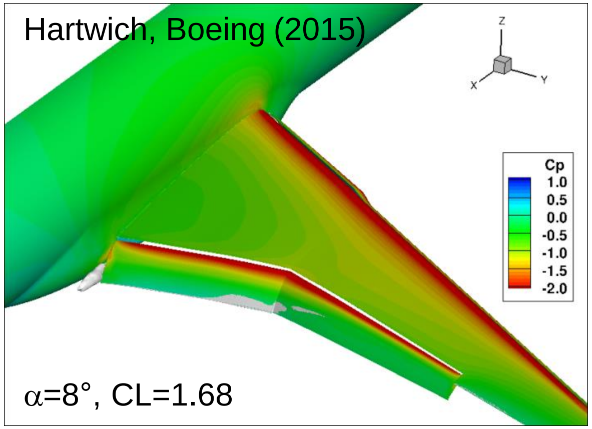
Approach

- Mechanization to simulate flight hardware
- Develop DAQ and test control system
- Measure torque, SCF/SGF shape and contact stress
- Correlate experimental and computational results

SCF & SGF Wind Tunnel Test Prep

Superelastic SMA Slat-Gap Filler (SGF)

CRM Baseline High-Lift Config.



Objective: Demonstrate reduction of slat noise via flexible SCF and SGF structural treatments on a modern wing w/ gain or no loss in aero-performance.

Approach

- Leverage planned 14x22 test of CRM for AFC
- Design & fabricate rigid & flexible SCF and SGF prototypes
- Test and compare aerodynamic and aeroacoustic performance with baseline high-lift system

Status

- Initial scaling study suggests geometric scaling appropriate for sub-scaled testing at flight Mach number and standard air conditions
- SCF profile design for CRM underway
- Periodic meetings being held to specify requirements & plan test

NASA