ARMD Transformative Aeronautics Concepts Program

CONVERGENT AERONAUTICS SOLUTIONS PROJECT

Spanwise Adaptive Wing

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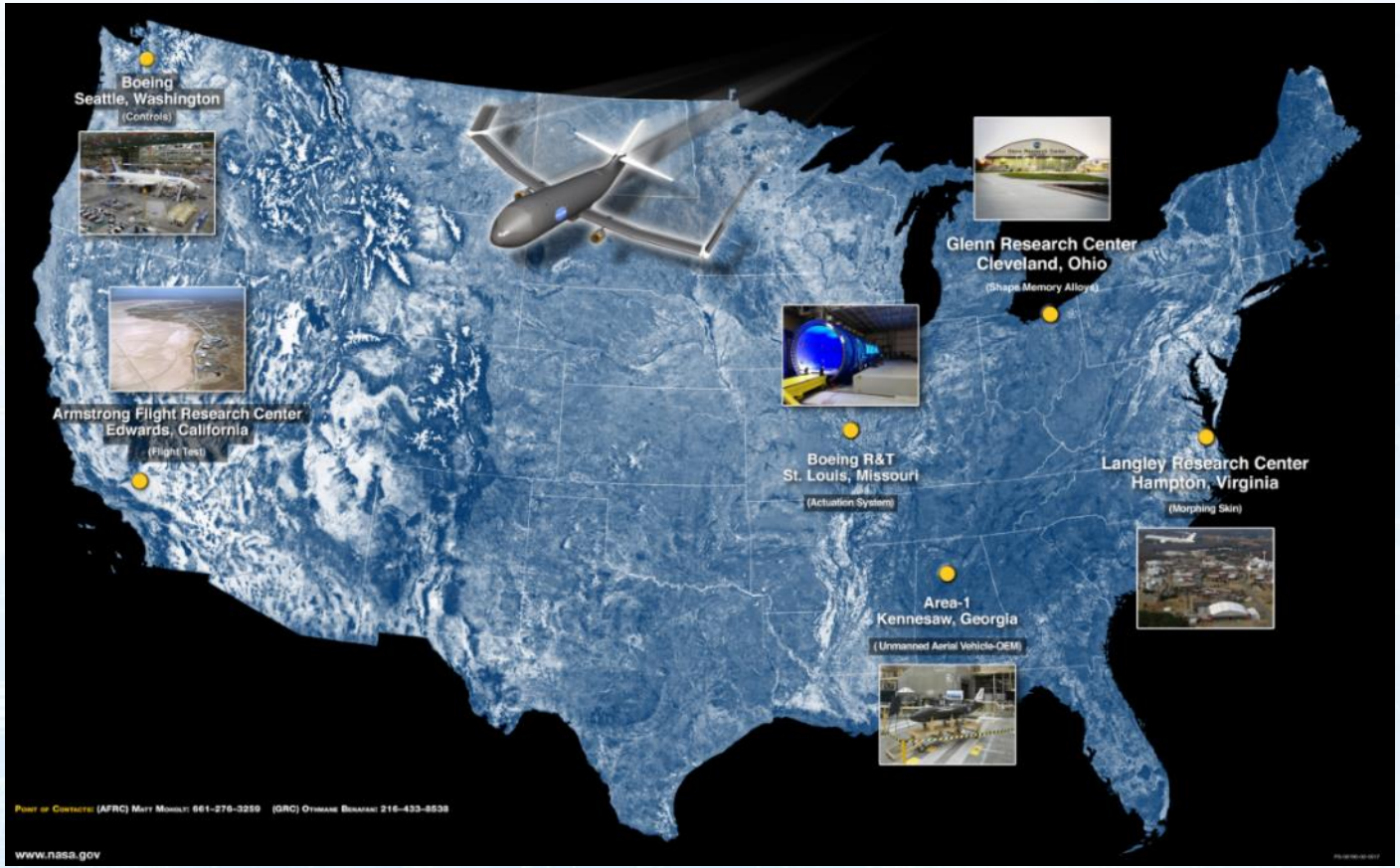
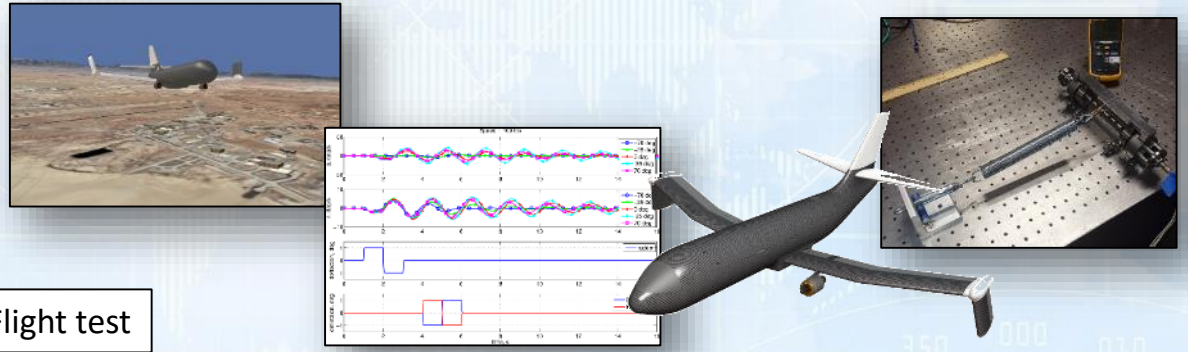
Enabling Reconfigurable Aircraft Through The **Spanwise Adaptive Wing** (SAW) Concept

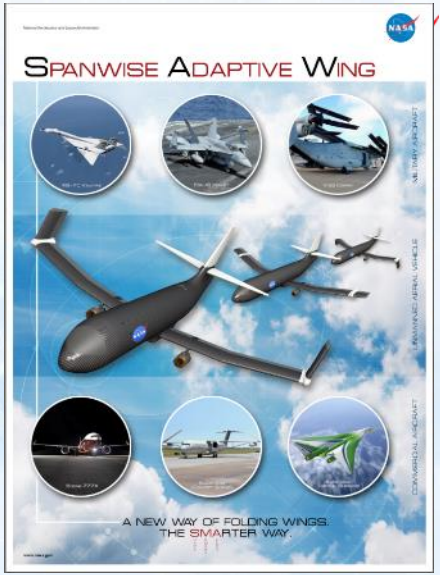
- Increasing aircraft efficiency by reducing the rudder through the incorporation of SAW
- Articulating the outboard portions of the wing via Shape Memory actuation
- Lateral-directional stability and control augmentation
- Supersonic - Increased compression lift and reduced wave drag
  - Enabler for supersonic flying wing design


Boeing
Seattle, Washington
(Controls)
Armstrong Flight Research Center
Edwards, California
(Flight Test)
Glenn Research Center
Cleveland, Ohio
(Shape Memory Alloys)
Boeing R&T
St. Louis, Missouri
(Actuation System)
Langley Research Center
Hampton, Virginia
(Morphing Skin)
Area-1
Kennesaw, Georgia
(Unmanned Aerial Vehicle-OEM)
www.nasa.gov

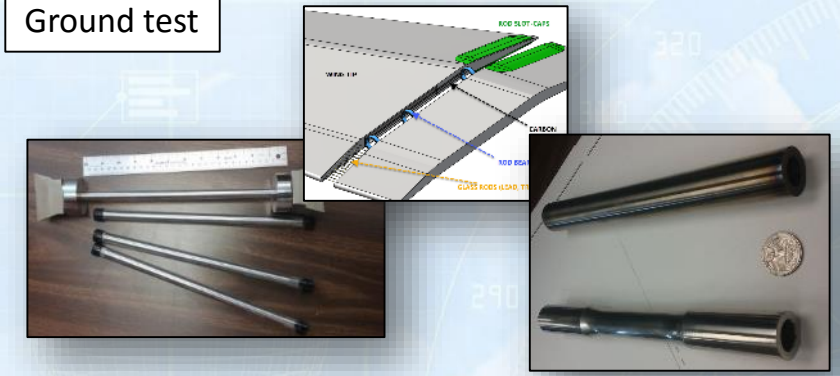
SAW Development Path



Flight test



Ground test



CAS Objective: to develop all of the sub-systems for full scale infusion

- Technology and tool development and validation
- Scale-up validation
- A plan for the next a larger demonstration in a more relevant environment

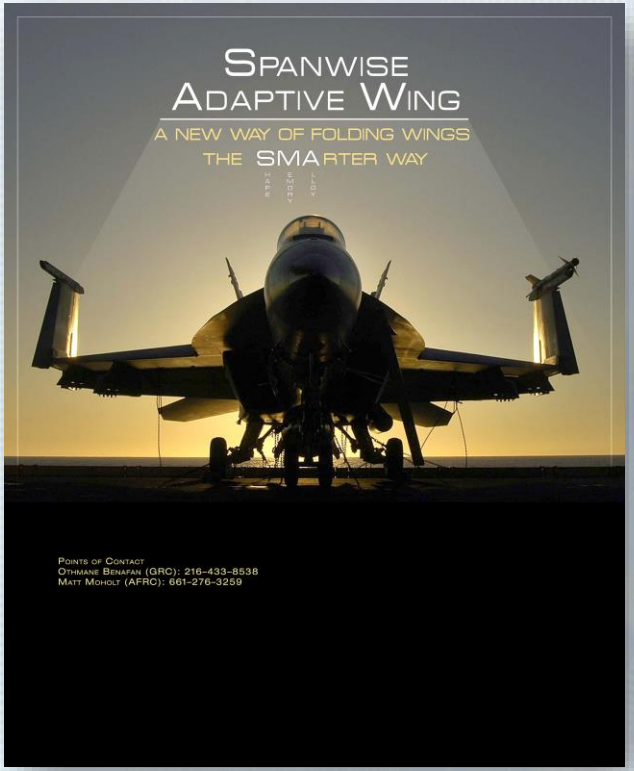
Reconfigurable Aircraft

Historical Perspective

Morphing Aircraft

Folding wing aircraft

Ground Folding



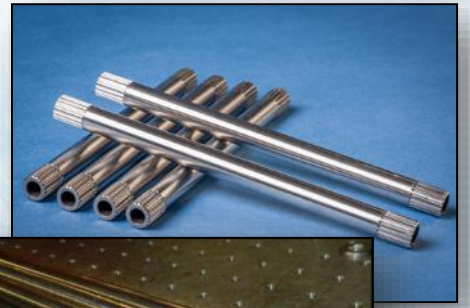
A New Way to Actuate

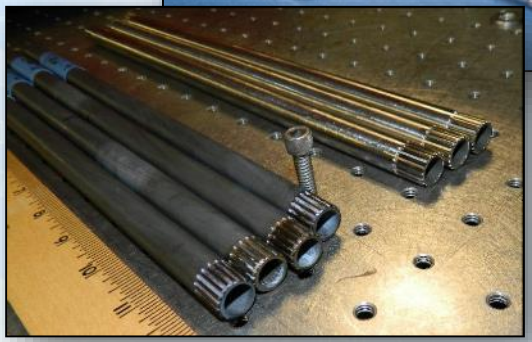
- Shape Memory Alloy (SMA)
  - NiTiHf

➢ **Alloys that have a "memory." These materials have the ability to remember and recover their original shapes with load or temperature.**

➢ **SMAs exhibit a solid-to-solid, reversible phase transformation**

➢ **Can be ALL-Electric driven**



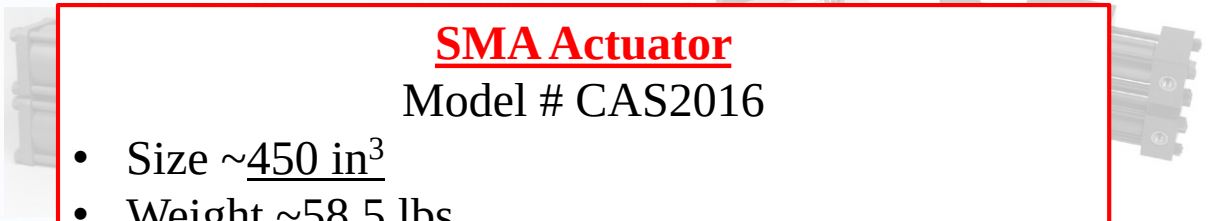


Multifunctional Properties

Current State-of-the-Art **Rotary Actuators**

HYDRAULIC ACTUATORS

PNEUMATIC ACTUATORS



Rotation (°)	
Footprint (in)	
Output Torque (i	
Operating tempe	
Weight (lbs)	

SMA Actuator

Model # CAS2016

- Size ~450 in^3
- Weight ~58.5 lbs
- Temperatures~ tunable based on alloy used
- Torque ~ 100,000 in-lbs
- Angle ~ 90 deg

Non-traditional – Revolutionary – Transformative

Assessment of Current Technology- With ARMD Thrusts in Mind

Current Technologies (hydraulic, pneumatic, or magnetic motors) do not provide a step-change towards "Big Leaps" in efficiency & environmental performance

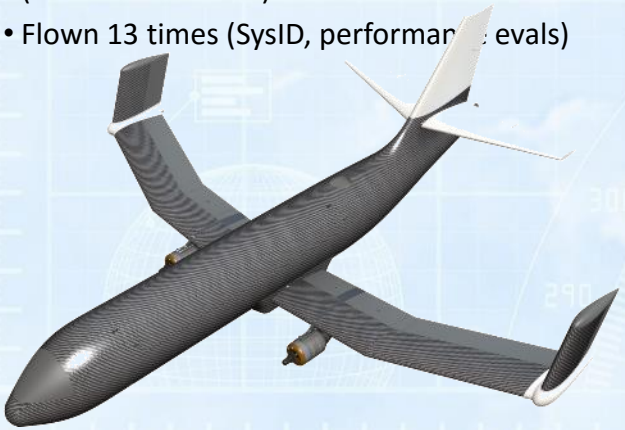
- **Heavy, and bulky – other options include gear boxes – large systems**
- **With SMA technology: 20% the weight & 15% the size of comparable hydraulic system**

Flight testing out of the box ideas

PTERA

Prototype-Technology Evaluation and Research Aircraft

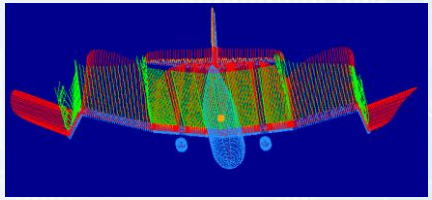
- Roughly based on an 11%-scale 737
- Baseline configuration has an 11.3ft span, 12ft length, and 4.3ft height
- ~200lb gross takeoff weight (40lb payload)
- Powered by two JetCat P200 turbojet engines (50 lbs thrust each)
- Flown 13 times (SysID, performan[illegible] evals)



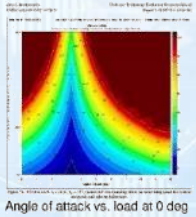
AREAI

Flight Test Experiment

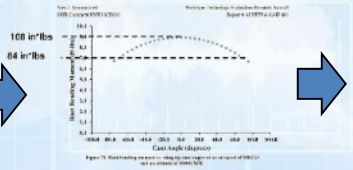
Trade space evaluation



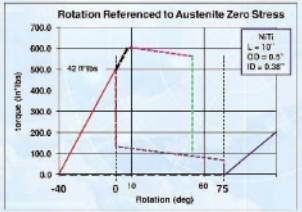
Aero analysis



Hinge Loads



Actuator Loads



Actuator Design

Configuration	Sweep Angle (Λ)	Wing tip Span (b_{wt})	C.G. shift (aft of root ¼-chord)	Wing tip Yaw Control (% of rudder @ 10.0° deflection)			Structural Assessment
				75.0°	-75.0°	0.0°	
1	0.0°	12.0 in	1.0 in	10.4	8.8	6.1	Yes
2	0.0°	15.0 in	1.0 in	12.4	10.7	9.3	Yes
3	0.0°	18.0 in	1.0 in	14.4	12.5	11.5	Maybe
4	10.0°	12.0 in	3.0 in	20.4	11.7	10.8	Yes
5	10.0°	15.0 in	3.0 in	25.9	16.0	13.2	Yes
6	10.0°	18.0 in	3.0 in	31.7	20.6	15.9	Maybe
7	20.0°	12.0 in	5.4 in	29.6	14.8	13.4	Yes
8	20.0°	15.0 in	5.4 in	38.5	21.5	16.6	Yes
9	20.0°	18.0 in	5.4 in	48.1	29.1	19.8	No
10	30.0°	12.0 in	8.0 in	38.3	17.3	16.2	Yes
11	30.0°	15.0 in	8.0 in	50.6	27.3	19.9	Maybe
12	30.0°	18.0 in	8.0 in	64.2	38.1	23.7	No

Baseline Values

Design Space Explored

Wing and Joint Design

For the PTERA demonstration SAW produces nearly **40%** of total rudder authority

Can this be used to reduce rudder size?

Flight Test

- Two flight campaigns on Edwards Air Force Base dry lakebed
- First flight late October/Early November 2017

WORKING TOWARD FULL SCALE

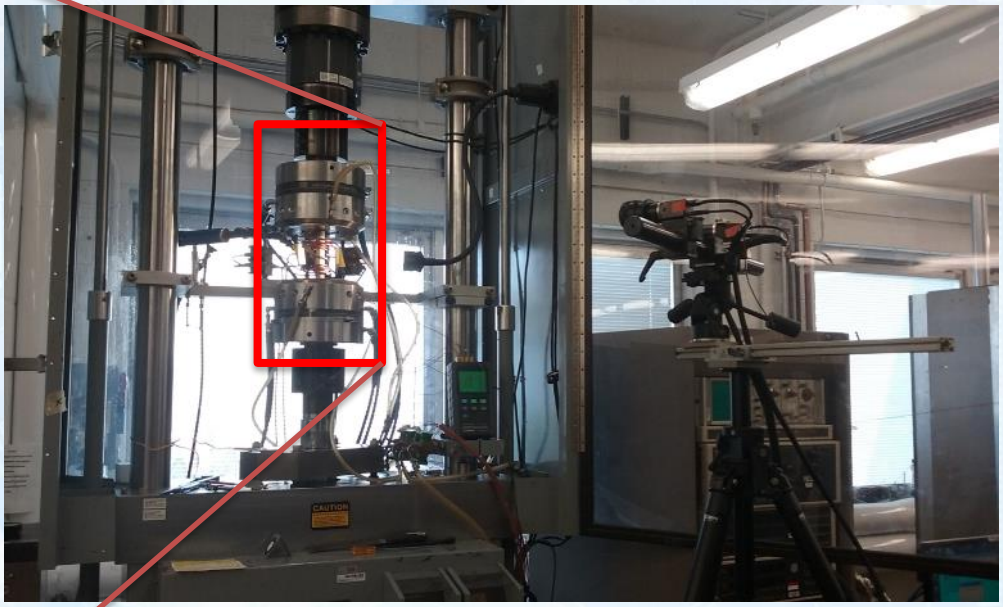
NiTiHf Alloy Processed in Large Scale

- ***60lbs of NiTi-20Hf material were melted***
  - Melting process scalable from 1 lbs to >100 lbs
  - Repeatable properties (for lab verification, actuator back ups, and future flights.
- ***Extrusion to rod and tubing***
  - From 4” to 0.5” in diameter and from 1.2” to 0.5” in diameter reduction
- ***Tubes drilled and splined***
  - Final form of actuator before training and instrumentation.

Ground Test: Large tube testing

- 1” tube
- 10” long

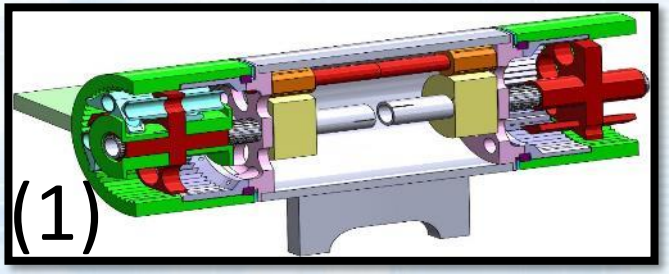
d

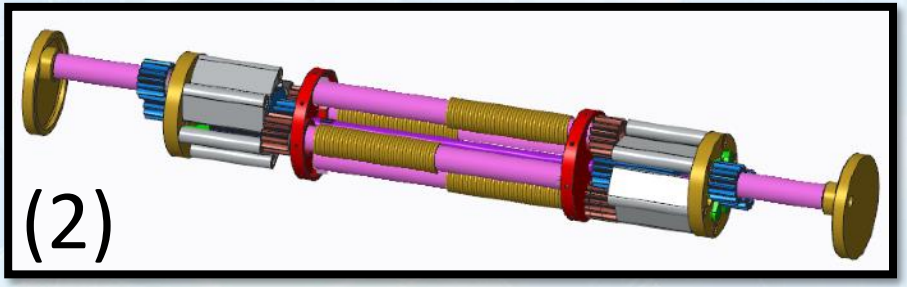


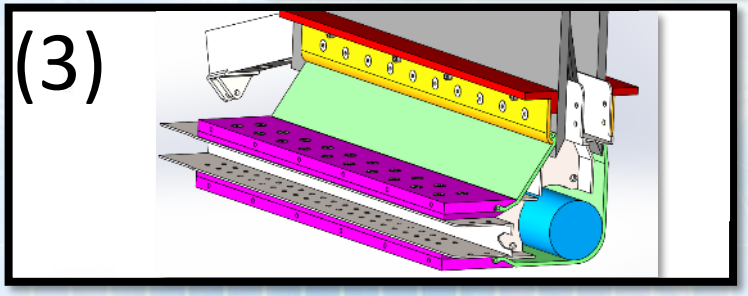
- 20,000 in-lbf test rig
- Fully instrumented for SMA large tube testing

3 Mechanisms for Ground Test

- Use 0.5” and 1” tubes
- Target for 90 degrees of rotation
- 5000 in-lbf torque
- Explore locking features







F-18 Demonstration?

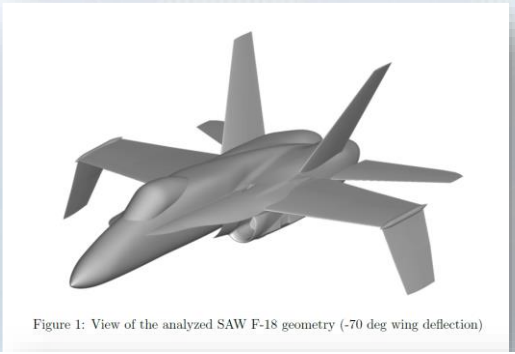


Figure 1: View of the analyzed SAW F-18 geometry (-70 deg wing deflection)

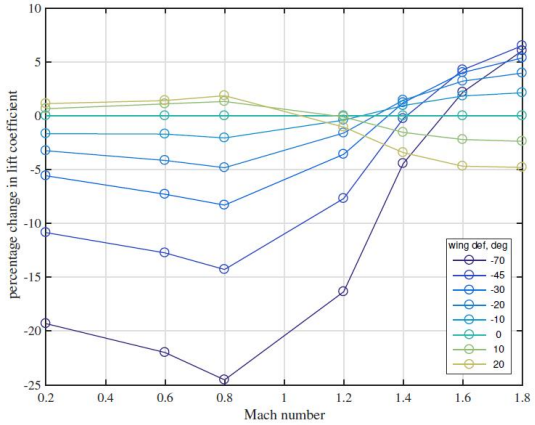


Figure 2: Percentage changes in lift coefficient for different wing deflections, from Cart3D

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