Variable Geometry Jet Nozzle Using Shape Memory Alloy Actuators

F. Tad Calkins
Boeing Commercial Airplanes, Aeroacoustics

James H. Mabe
Boeing Phantom Works, Flight Sciences

frederick.t.calkins@boeing.com – (425) 237-2831
James.h.mabe@boeing.com - (206) 544-5048

Morphing Overview

- Morphing Technologies **increase a system's performance by manipulating characteristics to better match the system state to the operating conditions (environment and task)**

- Aerospace applications
  - Landing gear
  - Flaps
  - Swing wing F-14, B1B
  - Concorde nose tilt
  - V22 Rotors rotate down

  - Mission Adaptive Wing
  - Active Aeroelastic Wing

Land gear

Flaps

V22 Osprey

Concorde

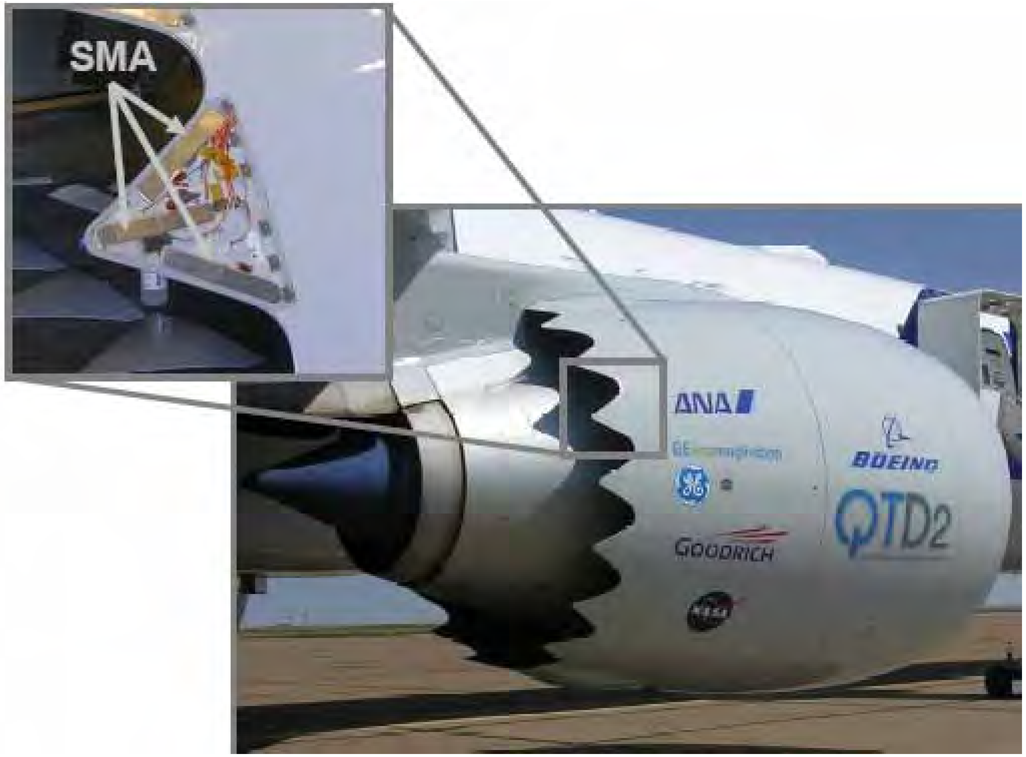
Morphing Aerostructures

- **Current "morphing" has disadvantages**
  - Even small structural changes are difficult
  - Requires heavy motors, hydraulics, structural reinforcement
  - Complexity
  - Expensive
- **"Smart" materials lead to new morphing concepts**
  - Fully integrated, distributed actuation
  - Conventional components given additional capability
  - Does NOT add weight
  - Simple mechanisms,
- **Smart materials applicable to morphing structures**
  - Piezoelectrics, electrostrictives, piezopolymers (electro elastic)
  - Magnetostrictives, ferromagnetic SMA (magneto elastic)
  - Shape memory alloys, polymers (thermal elastic)

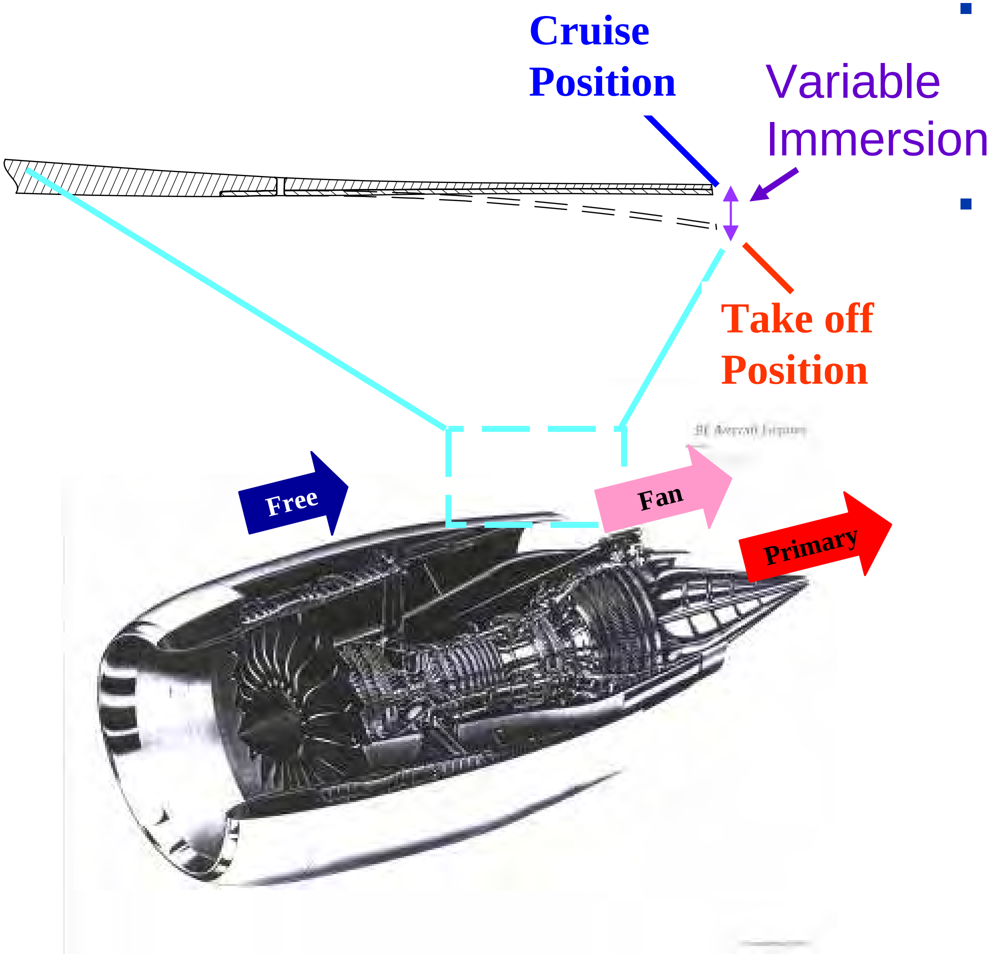
Shape Memory Alloy - Nitinol

Variable Geometry Chevrons

- **Reconfigurable engine nozzle fan chevron**
- **Apply morphing structures technology to enable efficient chevron shape change**
- **Shape Memory Alloy is key technology**
- **Example of new testing capability**
- **Mature technology TRL level 6-7**



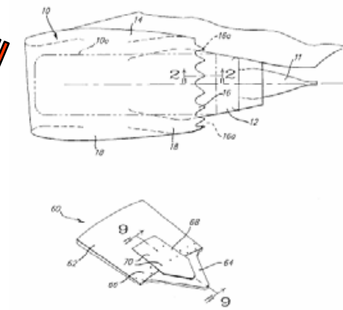
Variable Geometry Chevron Overview



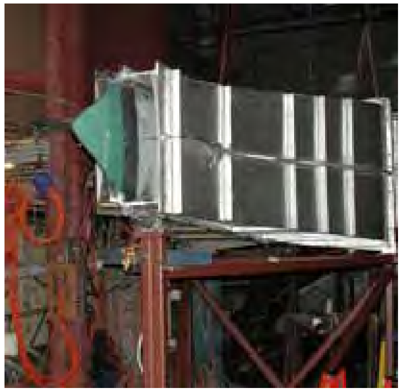
- **Goal: morph chevron shape to optimize engine performance**
  - **Community noise reduction**
  - **Shockcell noise reduction**
  - **Cruise performance**
- **VGC Program Milestones**

VGC Roadmap

Boeing VGC Patent
6,718,752
May 2002



NTF Concept Validation
December 2002



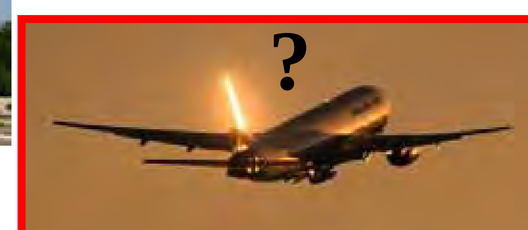
NTF2 QTD2 Design
April 2004

VGC GE-115B
Design and Fab

Flight Test
August 2005

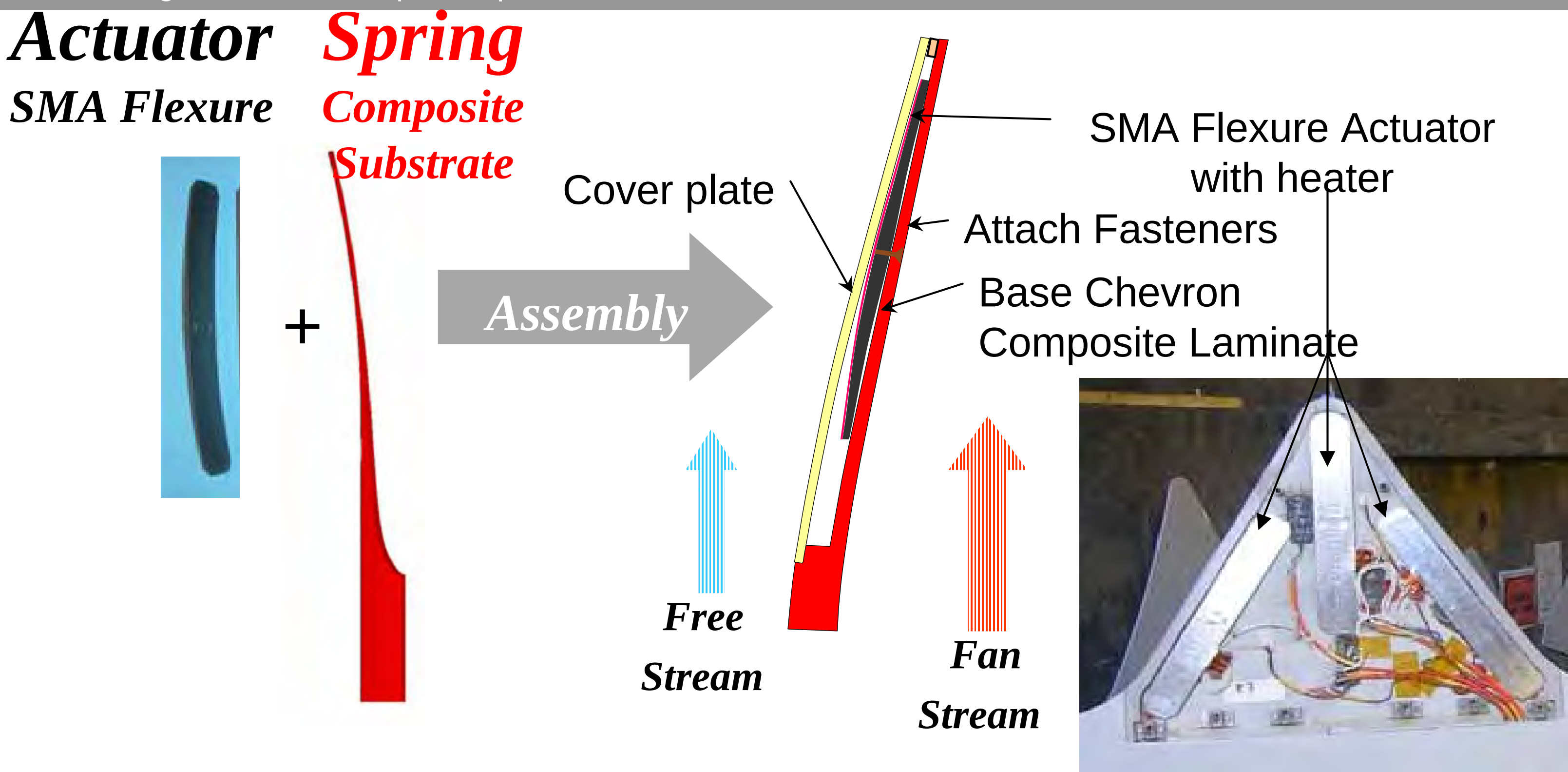
VGC Redesign

Static Engine Test
June 2006



Future Applications

VGC Design



– **Design**
  - **Simple, low part count**
  - **Low weight**
  - **Fully integrated**
  - **Variables**
    – **SMA Actuator properties**
    – **Substrate properties**
    – **Thermal environment**
    – **Geometry**

– **Fabrication**
  - **Thrust Reverser sleeve fabrication used production tooling and techniques**
  - **Nitinol actuator fabrication based on Boeing PW state of the art processes**

– **Thermal Management**
  - **Autonomous Operation**
  - **Controlled Operation**

Quiet Technology Demonstrator 2
VGC Flight Test Overview

Boeing Commercial Airplanes | **Aeroacoustics**

- All Nippon Airway 777-300ER w/ GE115B engine
- 6 flights over 5 days with 3 engine configurations
- Instrumentation, power, gages, and controller worked without failure
- Demonstrated autonomous (non-powered) operation
- Demonstrate individual VGC control
  - Closed loop controller maintained the prescribed in-flight tip immersions
- 9 Chevron configurations tested
  - Parametric study
  - Uniform immersion
  - Non uniform immersion

Static Engine Test

GE Peebles, OH, Engine Test Stand

- **3 days of testing June 2006**
- **2 engine configurations**
- **Noise performance evaluated**
  - 150’ polar arc
  - Phased Array
- **Demonstrated full autonomous operation**
- **Parametric studies of various immerions**
- **Completed all planned tests except engine operability study**

VGC Summary

- Successful full scale system development applying state-of-the-art morphing structures to jet noise technology
  - **Useful technology for testing (wind tunnel to flight)**
  - **First use of morphing structures technology to affect commercial aircraft noise performance**
  - **Rapid cutting edge technology development**
  - **Demonstration of SMA based actuators maturity**
- Successful rebuild of SMA actuators after flight test
- New DAQ and Control system using COTS software and hardware.
- Demonstrated autonomous and controlled actuation.
  Demonstrated ability to optimize aircraft performance at multiple flight conditions.

  Changes design philosophy: design for optimum performance at each condition of interest.

- Boeing is applying this technology to other aerospace applications including other noise problems