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 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

- Flaps
- Land gear
- V22 Osprey
- Concorde
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
Goal: morph chevron shape to optimize engine performance
- Community noise reduction
- Shockcell noise reduction
- Cruise performance

VGC Program Milestones
- Boeing VGC patent application 2002
- Concept developed and tested 2002-2005
- Flight test on 777-300ER, GE 115B engine 2005

Demonstrated
- Successful flight test

Autonomous Operation
- community noise reduction without cruise losses

Powered Mode
- Active design tool
- Potential of VGC Technology
VGC Roadmap

VGC GE-115B Design and Fab

NTF2 QTD2 Design April 2004

VGC Redesign

Flight Test August 2005

Static Engine Test June 2006

NTF Concept Validation December 2002

Boeing VGC Patent 6,718,752 May 2002

Future Applications
**VGC Design**

**Actuator**
- SMA Flexure
- Composite Substrate

**Spring**

**Assembly**
- Cover plate
- Attach Fasteners
- Base Chevron
  - Composite Laminate

**Free Stream**

**Fan Stream**

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**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

• 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

- 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