AIRCRAFT ENGINE ANALYSIS USING ADAMS

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Abstract

Turbine engines for jet aircraft are comprised of many complex subsystems. Variable stator vanes (VSV) and bleed valves are two such subsystems where friction, free-play and flexibility are not only necessary to function properly, but they greatly affect system performance and are very difficult to design for and analyze.

While the application of ADAMS to turbine engines is relatively new, these problem analysis areas, friction, free-play and flexibility, are the strengths of ADAMS. Variable stator vanes and bleed valves are two subsystems where the analysis capabilities of ADAMS are extremely valuable in measuring system parameters such as internal loads, engine schedule, binding and leakage. This paper will demonstrate ADAMS modeling capabilities, as well as simulation results for both subsystems.

Introduction

Aircraft engine companies are facing increased pressure from airframe manufacturers to deliver lighter, higher performance engine designs within a shorter design cycle. Traditionally, engine manufacturers utilize a build-and-test approach, where physical testing is not only very expensive, it is extremely time consuming. Now they are turning towards virtual prototyping, where they can test many designs and come up with an optimum system configuration before building the first physical prototype.

The purpose of this paper is to give a brief description of two subsystems on a turbine engine for jet aircraft, describe in general, the modeling methods used in ADAMS, and present simulation results showing what can be expected from an ADAMS simulation.

Variable Stator Vane (VSV) System

The VSV system is located approximately one third of the way back from the front of the engine. The function of the VSV system is to control the airflow through the engine. The VSV system consists of an actuation system and three to five individual “stages”. Figure 1 shows the actuation system and one individual stage from a three-stage system.

The actuation system can be categorized as a single point or dual point actuation system, depending on the number of actuators. The actuator stroke is a function of engine speed and is connected to the individual stages by a bellcrank and drag links.

An individual stage of the VSV system consists of a series of vanes, which are distributed radially around the circumference of the engine, with each vane connected to a vane arm.

All of the vane arms are pinned to the unison ring, which is rotated about the centerline of the engine by the drag link from the actuation system. As the unison ring is rotated, all of the vanes should rotate an equal amount. Figure 2 shows a close-up of one individual stage. The unison ring is designed to be very light, therefore it is generally quite flexible. To prevent ovalization of the unison ring during operation, rub pads are placed on the engine case, at the inner radius of the unison ring, to keep the ring circular. Generally, there is approximately 0.005-0.010" clearance between the rub pad and the unison ring.

Variable Stator Vane (VSV) System

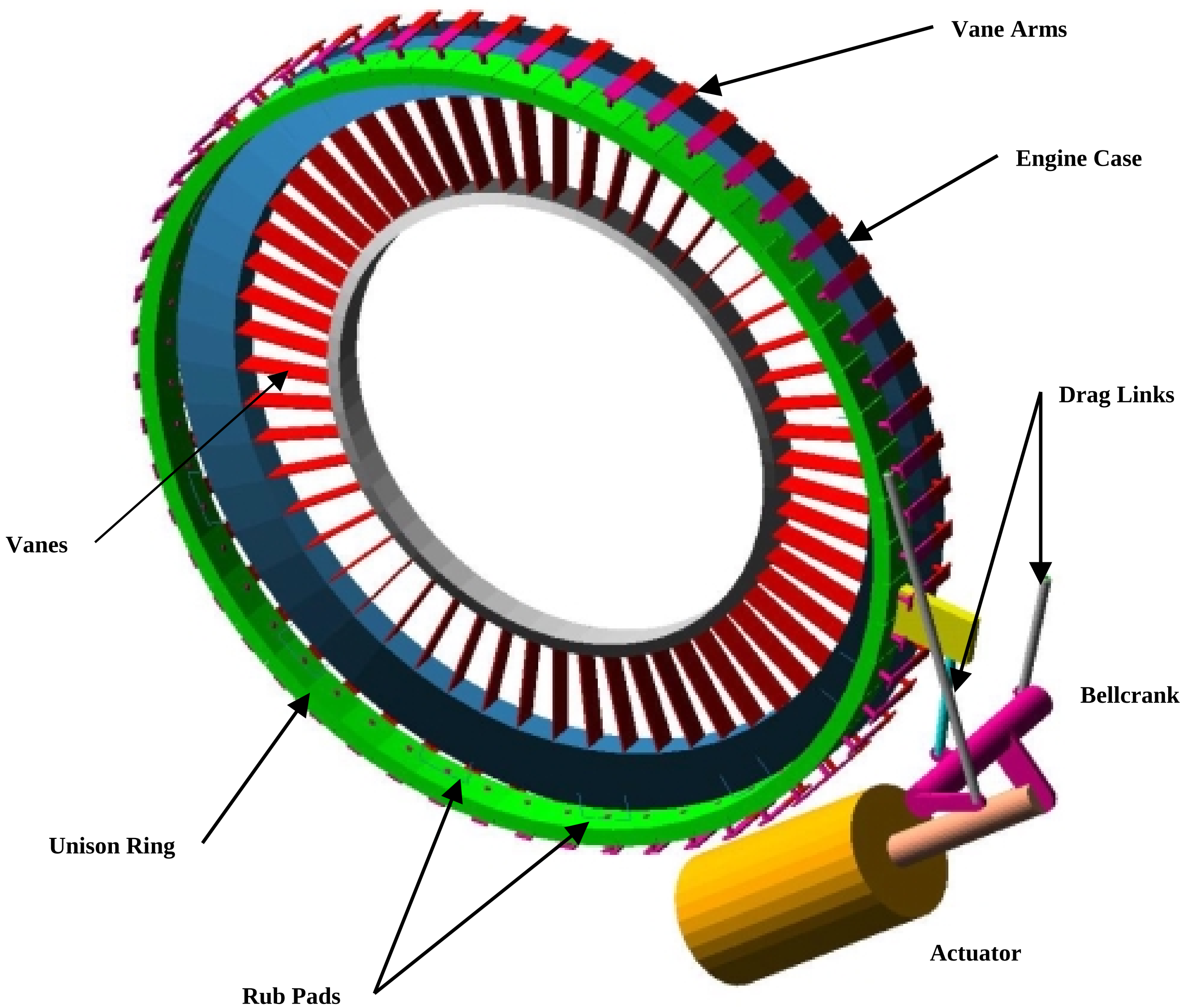

Figure 1

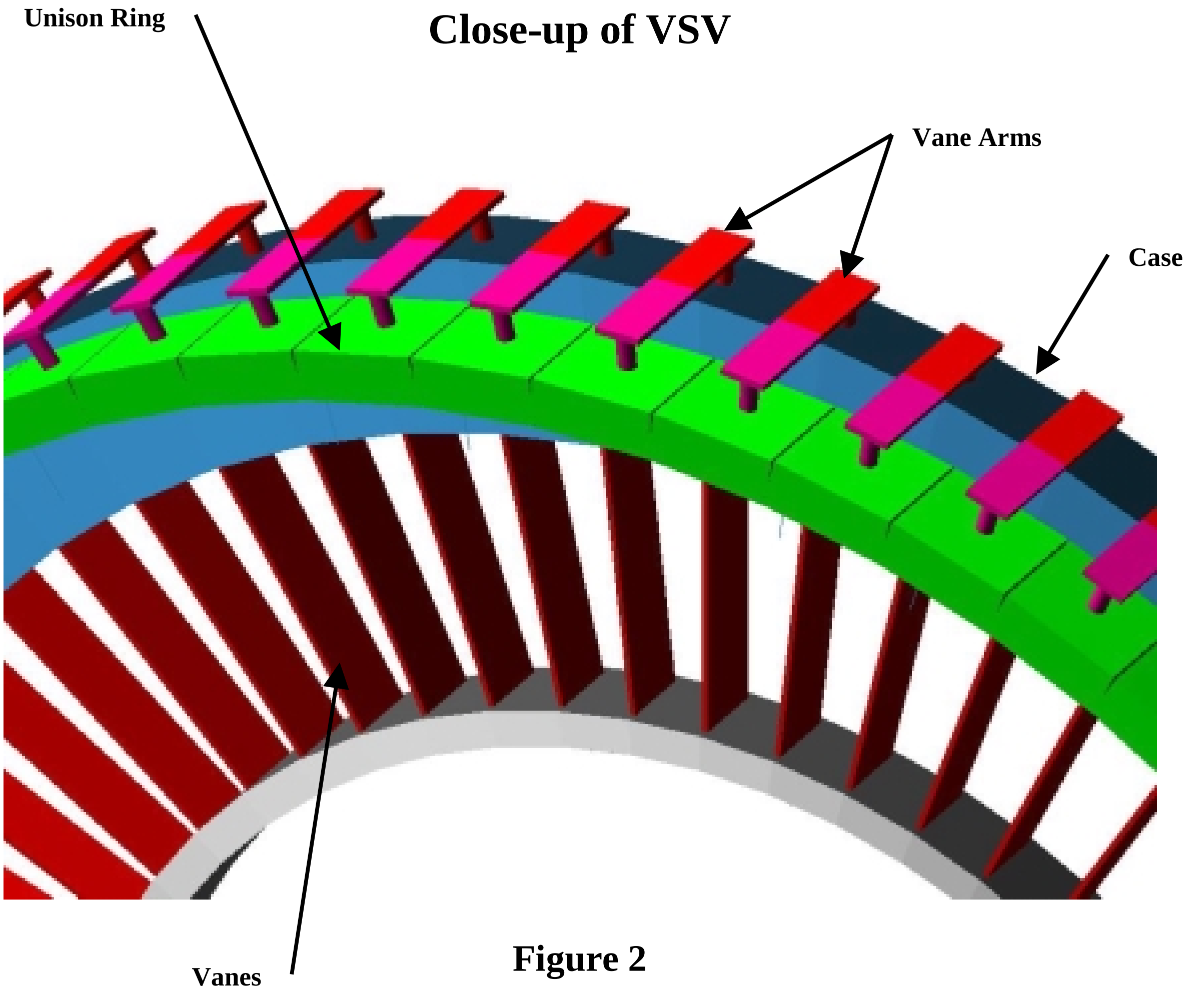

Figure 2

Loading on the VSV system comes from two main sources: 1.) aerodynamic loads due to the high volume of airflow through the system, and 2.) friction, especially at the rub pad/unison ring interface.

ADAMS VSV Model

When designing and/or analyzing the VSV system, the problem areas in general are predicting vane angles and internal loads. With the introduction of flexibility for major components and friction and free-play at the structural joints, the vane angles start to vary around the circumference of the engine. This leads to uneven airflow through the engine, affecting engine performance and even causing compressor stalls. The deviation of the actual vane angle to the kinematic (or "perfect") vane angle is called the vane angle error.

When modeling the VSV system in ADAMS, the unison ring and the vane arms were modeled using ADAMS beams. All of the structural joints were modeled using a V-force (to represent pin/hole contact) and S-force (to represent friction) to account for free-play and friction. By using these modeling elements/techniques, design variables can be used to represent structural (unison ring and vane arm beam properties) and geometric (hole and pin diameters) properties. This allows the analyst to use the model to perform design studies to see how certain parameters affect overall system performance.

VSV Simulation Results

The ADAMS model for the complete VSV system (actuation system and three stages) has 502 parts and 2949 DOF. This model takes approximately one hour to simulate one complete cycle (actuator full extension and retraction) on a 750 MHZ PC.

The results from a simulation contain all the displacements, velocities, accelerations and forces in the system. More specifically, the results contain all the internal loads on all the components, as well as vane angle errors for each stage. Figure 3 shows the total load (normal and friction force) from the 12 rub pads on the unison ring, while Figure 4 shows the vane angles around the circumference of one stage as a function of actuator stroke (every 45 degrees, starting at TDC).

These results can be used to optimize component shapes, tolerances and kinematics (to achieve the optimum air flow through the engine).

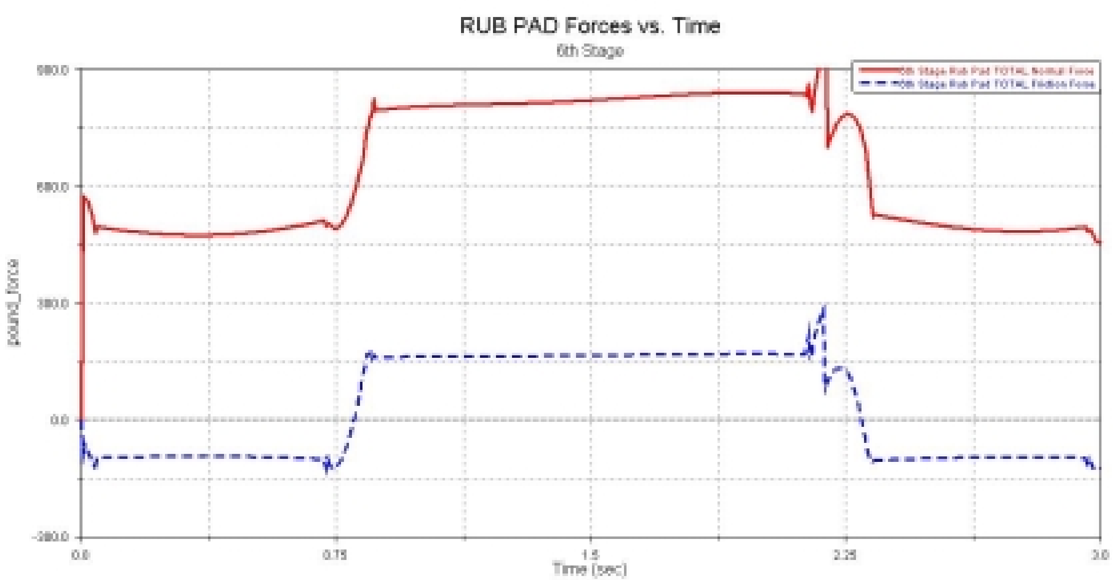

Figure 3

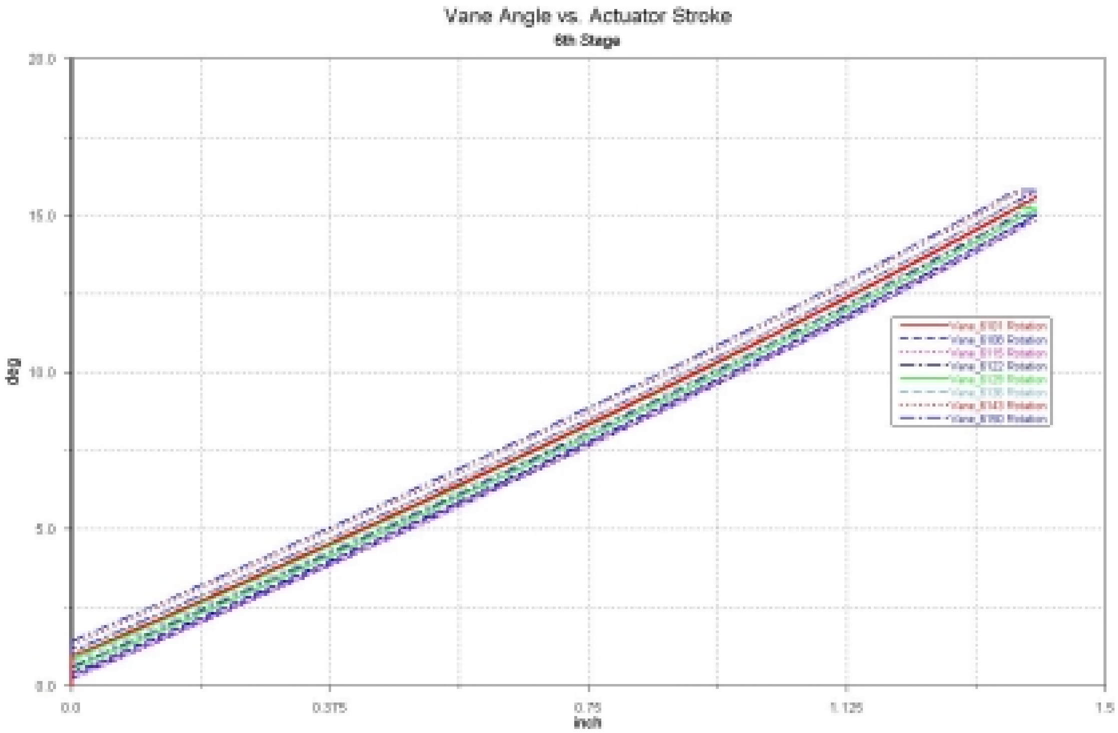

Figure 4

Low Pressure Compressor Stability Bleed Valve

The bleed valve system is located very close to the front of the engine (approximately one fifth of the way back). The function of the bleed valve is to regulate the pressure in the low-pressure compressor section of the engine. Figure 5 shows the bleed valve system.

The bleed valve system is comprised of the valve, actuator, bellcrank, rollers & cam slots, and rub pads, which are an integral part of the engine casing. The actuator position is a function of many factors, including engine speed, temperature, and pressure differential. As the actuator extends, it pushes on the bellcrank, which in turn, applies a tangential force on the valve. The valve motion is controlled by a series of rollers and cam slots. As the valve rotates about the centerline of the engine, it translates away from the engine casing, thereby creating a gap and allowing air to flow from the high-pressure area inside of the valve to the low-pressure areas outside of the valve. As seen in the VSV system, rub pads are located around the inner circumference of the valve to limit the shape change of the valve. Figure 6 shows a close-up of the valve, rollers & cam slots, and rub pads. Loading on the valve comes from air pressure inside of the valve. The pressure acts radially outward on the valve as well as along the axis of the engine. The pressure helps to push the valve open, and opposes the valve closing. Pressure differentials up to 36 psi can be seen across the valve.

Bleed Valve System

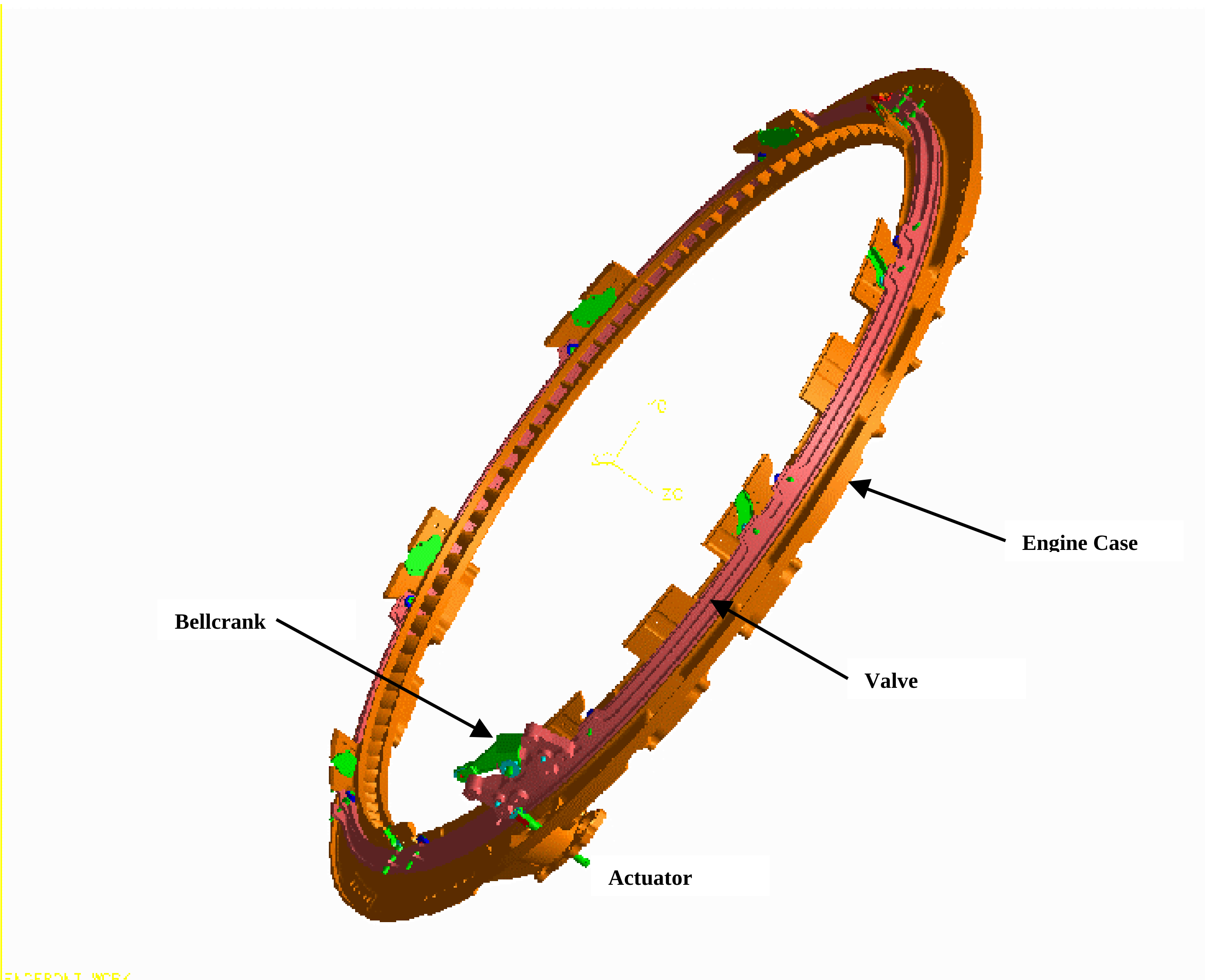

Figure 5

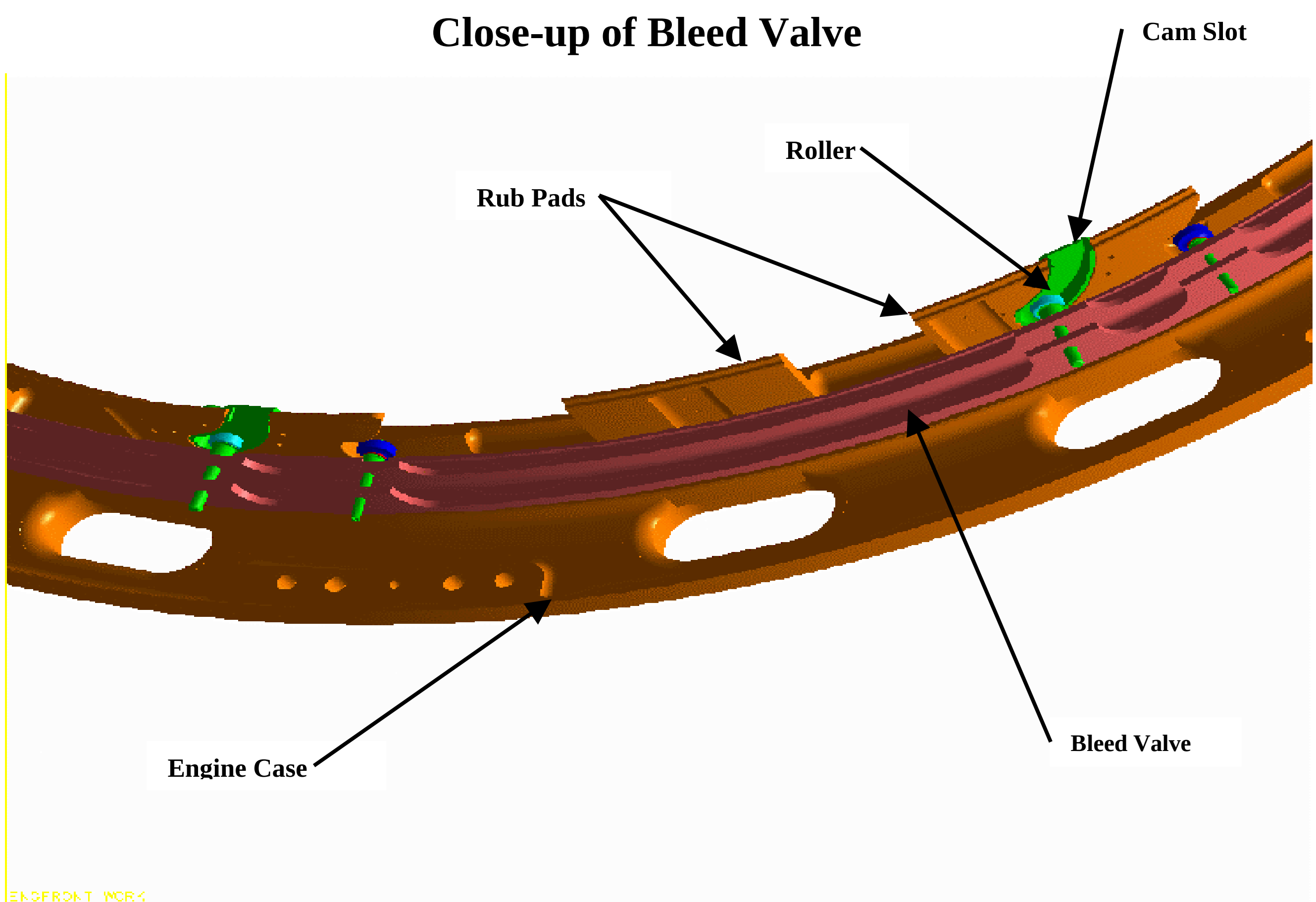

Figure 6

ADAMS Bleed Valve Model

When designing a bleed valve system, it is very difficult to predict the loads on the system. If the forces between the rub pads and the valves are too high, the valve may bind up and not seal properly, causing leakage between the valve and the casing. Since the valve is very lightweight and flexible, there is a wide range of loads seen on the rollers, depending on location.

In order to model the flexibility of the valve correctly in ADAMS, an FEM of the valve was constructed using MSC/NASTRAN. This FEM was used to create a flexible body for the valve, using the ADAMS/Flex toolkit.

A circle-to-circle contact routine was used to model the roller to cam slot, while V-forces were used to model free-play and friction between the valve and rub pads. Finally, V-forces were distributed around the circumference of the valve to model the pressure load on valve, and contact between the valve and casing.

Bleed Valve Simulation Results

Figures 7 & 8 show two examples of the types of output that is available from the bleed valve simulation. Figure 7 shows the load-stroke plot for the actuator. The plot shows it takes almost four times the force to close the valve than it does to open.

Figure 8 show the maximum load on the rollers during one complete open/close cycle. For this particular design, the 720 lbs seen on roller 8 exceeded the maximum bearing capacity, and a new roller/bearing configuration had to be selected.

Not only can the ADAMS model be used to design the optimum structural configuration, such as number and location of rub pads or the cross section of the valve, it can also be used to verify system functionality (make sure the mechanism works properly and doesn't bind up during any of the loading conditions), or determine the proper rigging load (preload on the system that prevents leakage during the closed condition).

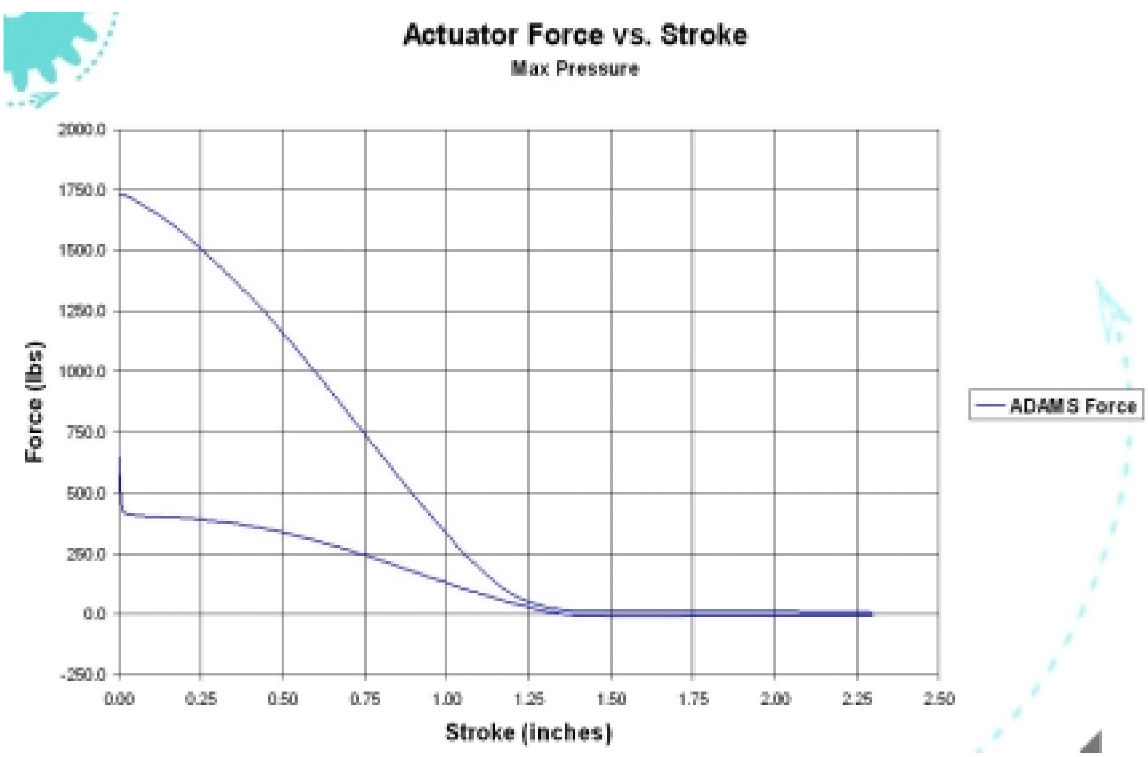

Figure 7

Cam Follower Loads on Bleed Valve

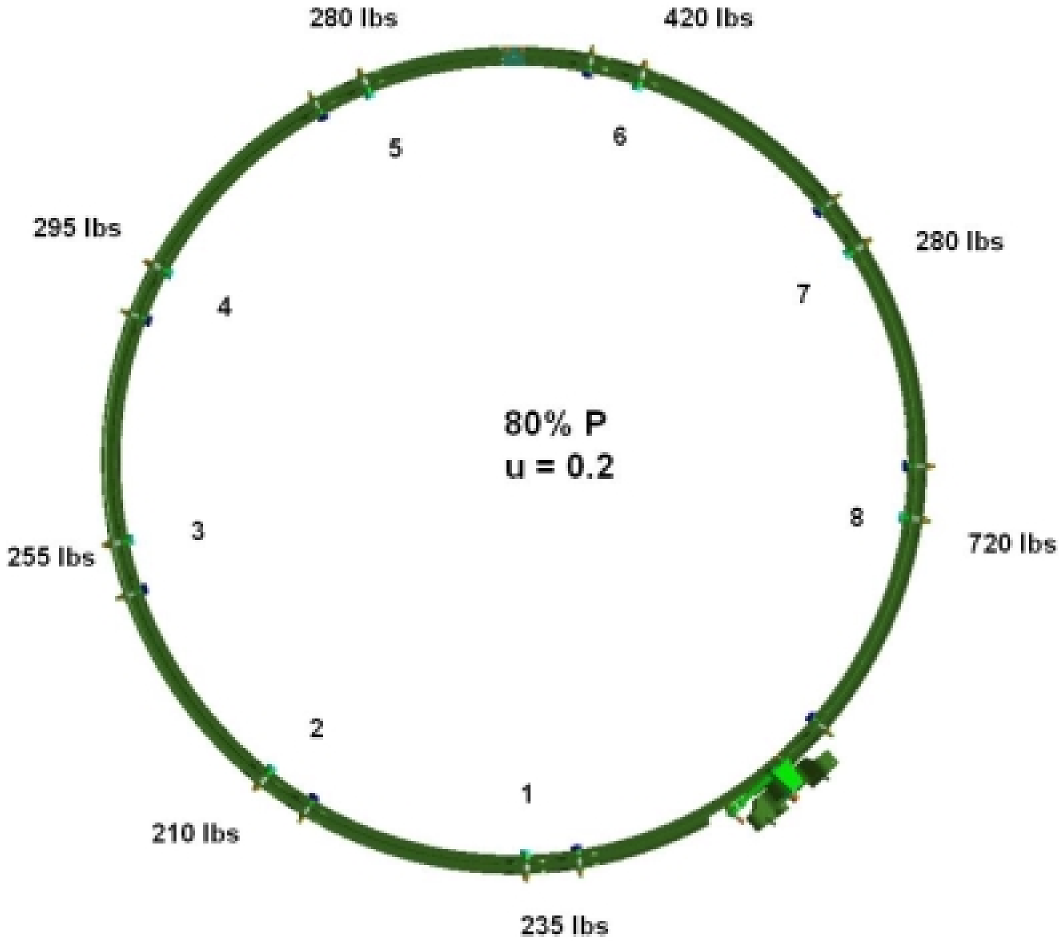

Figure 8

Conclusion

In summary, aircraft engine manufacturers, forced with improving engine designs at lower costs and shorter design cycles, are turning towards virtual prototyping to reduce the number of costly physical prototypes.

This paper presents results of ADAMS modeling and simulation for two complex mechanical subsystems on a turbine engine for jet aircraft. ADAMS integrates the individual components into a single system model and is a viable tool for analyzing complex mechanical subsystems. These models can but used to predict component and system behavior, optimize component and system parameters, as well as verify system functionality. This will ultimately help engine manufacturers reduce their development costs and reduce design cycles.

ADAMS

Aircraft Engine Analysis Using ADAMS

November 15-17, 2000

European ADAMS User Conference

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ADAMS

Aircraft Engine Analysis Using ADAMS

- ADAMS - Aerospace Applications
- Variable Stater Vane (VSV) System
  - Problem description
  - Modeling/Simulation Notes
  - Results/Summary
- Bleed Valve System
  - Problem description
  - Modeling/Simulation Notes
  - Results/Summary
- Summary

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ADAMS - Aerospace Applications

- Landing Gears
  - **Retraction analysis**
  - **Complete loads analysis**
  - **Shimmy analysis**
  - **Drop testing**
  - **Tie down analysis**
- Braking Systems
  - **Whirl analysis**
  - **Squeal analysis**

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ADAMS - Aerospace Applications

- Engines
  - **Variable stator vane (VSV) actuation system**
  - **Bleed system**
  - **Bearing analysis**
- Cargo Doors
  - **Verify system functionality**
  - **Loads analysis**

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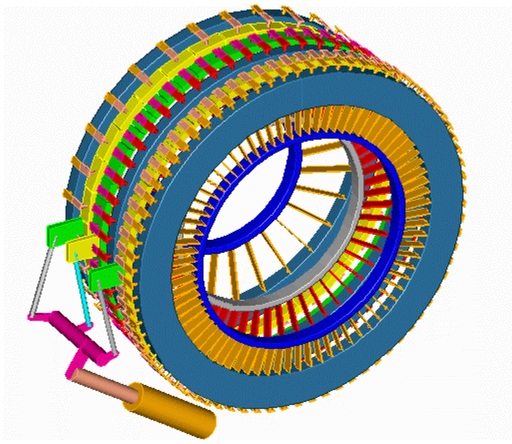
VSV Actuation System



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VSV - Problem Definition

- **Problem in General**
  - Inability to predict vane angles
  - Difficulty predicting structural loads on new designs
  - Inability to determine engine schedule
  - Difficulty estimating the effect of proposed engine changes on structural and fatigue loads
- **Specific Analysis Problems**
  - Flexibility in mechanism components
  - Free-play in structural joints
  - Friction in structural joints

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Project Metrics - Industry

- Approximately $20 K to $30 K per hour to test
- Long lead times to calibrate new engine designs (2-3 months, typically)
- Very expensive to fix fatigue related failures

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ADAMS Simulation - Model Configuration

- Complete System Model
  - Flexibility for selected components
  - Friction and free-play at structural joints
  - Bump stops limit shape change of flexible ring
  - Aerodynamic loads applied to individual vanes
  - Actuator/bellcrank actuation mechanism
- ADAMS model notes (complete 3 stage model)
  - Free play, friction, & flexibility
  - Approximately 3000 degrees of freedom
  - Approximately 3 hours solution time for full cycle simulation
  - Approximately 70 design variables

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VSV Summary

- **Variable Vane System Sensitive Parameters**
  - **Friction parameters**
  - **Bump stop clearance**
  - **Ring section properties**
  - **Tolerances in pin/bushing joints**
  - **Aerodynamic loading**

- **Major differences in analysis with/without: flexibility, friction and free-play**

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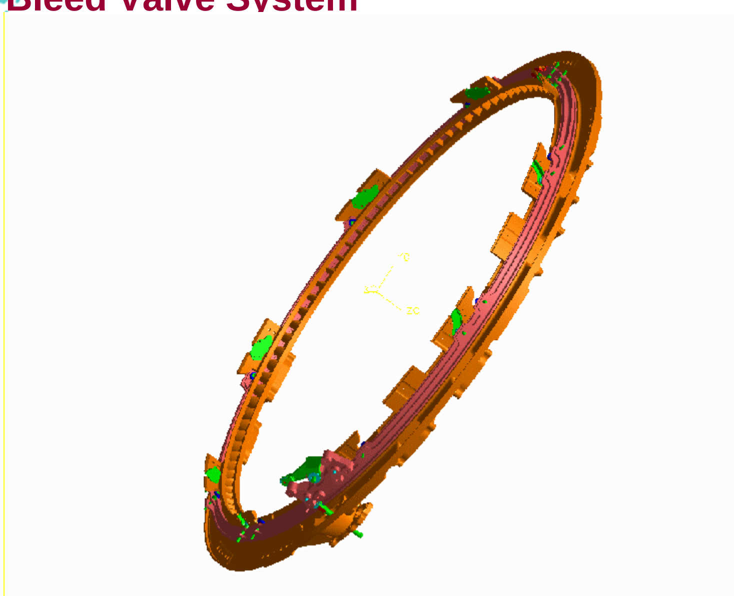
Bleed Valve System



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Bleed Valve: Problem Definition

- **Problem in General**
  - Rapid wear of cam/follower bearings
  - Difficulty predicting structural loads on new designs
  - Inability to determine proper rigging load and leakage
  - Difficulty estimating the effect of proposed design changes on durability, binding and leakage
- **Specific Analysis Problems**
  - Flexibility in mechanism components
  - Free-play in structural joints
  - Friction in structural joints

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Bleed Valve: ADAMS Simulation

- **ADAMS model notes:**
  - Flexible bleed valve using flex_body from NASTRAN FEM
  - Cam/roller contact with free-play
  - Valve/bumper contact with free-play
  - Valve seal contact with case
  - Applied pressure load on valve
  - Approximately 25 design variables
- **Simulation notes:**
  - Approximately 3 hours solution time for full cycle simulation
  - Ability to run design studies
    - Determine factors that affect overall system performance
  - Measure any displacement, velocity, acceleration or force at any location in the system

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Bleed Valve Summary

- Inability to incorporate "true" friction (as a function of normal force and relative surface velocity) in FEM's
- Excellent correlation between ADAMS analysis and test data
  - Actuator & bearing loads
  - Valve deflections
- Utilize the virtual prototype to "test" new concepts for reducing stresses and bearing loads

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Summary

- ADAMS is a viable tool for analyzing complex engine mechanisms (provides dynamic simulation of highly complex and non-linear mechanical models)
- Utilize expertise/methods learned in other disciplines, i.e. automotive, power transmission, etc.
- Integrates the actuator, linkages, vanes, and flexible rings into a single system model

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Summary

- "Measure" any force, displacement, velocity and/or acceleration in the system
- Excellent correlation with test results
- Correlated models reduce number of physical prototypes:
  - Cheaper, safer, faster
- Saves $$$$$

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