AN AIRCRAFT MODAL SUPPRESSION
YAW DAMPER SYSTEM

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO
Objectives of Modal Suppression Yaw Damper

- Control Dutch Roll Response
- Provide Good Turn Coordination
- Suppress Flexible Body Modes
  - Improve Lateral Ride Comfort
PSD of the Lateral Acceleration at the Aft Galley

PSD, g²/rad/sec

Peak at 0.007
747
PSD of the Lateral Acceleration at the Pilot Station

PSD,
$g^2/\text{rad/sec}$
747
Plant Model for Aft Filter Design

Plant

Rudder Command

Disturbance

Dryden Gust Model

Servo

Power Control Actuator

Airplane Structural Model

Rudder Command

Aft Sensor
747
Transfer Function
Rudder Command to Aft Galley Sensor

Phase, degrees

Gain, dB

Frequency, Hz
Transfer Function for the Aft Cabin Sensor Filter

Phase, degrees

Gain, dB

Frequency, Hz
Plant Model for Pilot Station Filter Design
747 Transfer Function
Rudder Command to Pilot Station Sensor

Phase, degrees

Gain, dB

Frequency, Hz
Closed-Loop System
PSD of the Lateral Acceleration at the Aft Galley

PSD, $g^2/\text{rad/sec}$

Closed-Loop Airplane
Basic Airplane

Frequency, Hz
PSD of the Lateral Acceleration at Pilot Station

PSD, $g^2/\text{rad/sec}$

Frequency, Hz

- - - - - Closed-Loop Airplane
- - - - - Basic Airplane
747-400 / PW4000 (RT401)
Modal Suppression Yaw Damper Flight Test 4-15
6 July 1988 (15:14:00)

- **Airplane Configuration**

  - **Typical Revenue Payload with FWD CG**
    - OEW 365.8 K @ 26.1 % MAC
    - ZFW 402.9 K @ 17.6 % MAC
    - T/O GW 685.0 K @ 10.0 % MAC
    - @ Test Condition 586.5 K @ 12.8 % MAC

- **Fuel Loading**

<table>
<thead>
<tr>
<th>T/O</th>
<th>Flight Condition</th>
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<tbody>
<tr>
<td>% Full</td>
<td>Approx.</td>
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<tr>
<td>Center Wing</td>
<td>45</td>
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<tr>
<td>Main #1</td>
<td>100</td>
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<tr>
<td>Main #2</td>
<td>100</td>
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<td>Main #3</td>
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<td>Main #4</td>
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<td>Res #2</td>
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<tr>
<td>Res #3</td>
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<tr>
<td>Stabilizer</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Flight Condition (Turbulence)**

  \[ M = .45 \]

  \[ h = 8000 \text{ ft} \]
747-400
Power Spectrum
Vertical Acceleration - Right Wingtip

Power Spectral Density, g²/Hz

Modal Suppression OFF

Modal Suppression ON
747-400
Power Spectrum
Vertical Acceleration - Left Wingtip

Power Spectral Density, $g^2/Hz$

Modal Suppression OFF

Modal Suppression ON
747-400
Power Spectrum
Lateral Acceleration - Fin Tip

Modal Suppression OFF

Modal Suppression ON

Frequency, Hz

Power Spectral Density, g²/Hz
747-400
Power Spectrum
Vertical Acceleration - Left Stabilizer Tip

Modal Suppression OFF
Modal Suppression ON

Power Spectral Density, $g^2/Hz$

Frequency, Hz
747-400
Power Spectrum
Lateral Acceleration at Pilots Seat

Power Spectral Density, $g^2/\text{Hz}$

Frequency, Hz

Modal Suppression OFF

Modal Suppression ON
747-400
Power Spectrum
Lateral Acceleration at BS 2300

Power Spectral Density, g²/Hz

Frequency, Hz

Modal Suppression OFF
Modal Suppression ON
Power Spectral Density, 1.0E16 (in-lb)^2/rad/in

767-300
Power Spectrum
Fuselage Lateral Bending Moment
Aft Pressure Bulkhead  BS 1714

- Modal Suppression OFF
- Modal Suppression ON

One Yaw Damper ON in both cases *

* Minimum Dispatch Requirement
Power Spectral Density,
1.0E16 (in-lb)^2/rad/in

Modal Suppression OFF
Modal Suppression ON
One Yaw Damper ON in both cases *
* Minimum Dispatch Requirement

Lateral Gust Spectrum
Vertical Fin Root Bending Moment
Summary Comments

- The major contributor to lateral ride discomfort is the dutch roll mode which accounts for about 60 percent of the acceleration in the aft body.

- Sideslip Rate is used to control dutch roll. In addition, a fast frame time microprocessor, 15 msec, is used together with a wide bandwidth servo, 70/(s+70). The original yaw damper system, without modal suppression, used a 51 msec frame time and a low bandwidth servoactuator, 35/(s+35). The frame time and servo change was made to allow better phase adjustment for the dutch roll and the flexible mode filters.

- There are two (2) structural modes of importance at the Aft Galley location: 1.75 and 2.0 Hz.

- There is one mode of importance at the Pilot's Station: 3.2 Hz.

- The Aft Body filter was designed first: The phase required was +40 degrees at 1.8 Hz. The total phase of the airplane plus controller was made equal to 0 degrees.

- The Fore Body filter was designed next: The phase was -278 degrees at 3.2 Hz. The total phase of airplane plus controller again was made equal to 0 degrees.

- The Aft Body and Vertical Tail root bending moments are not significantly affected by the Modal Suppression System; therefore, there is essentially no degradation in fatigue life.
Credits


Ho, J. K.; Cooper, S. R.; Tran, C. B.; Chakravarty, A.: On the Design of Robust Compensators for Airplane Modal Control

Ho, J. K.; Goslin, T. J.; Tran, C. B.: Aircraft Modal Suppression System: Existing Design Approach and its Shortcomings

Tran, C. B.; Goslin, T. J.; Ho, J. K.; Chakravarty, A.: Aircraft Fore and Aft Modal Suppression System