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# ANALYTIC REDUNDANCY MANAGEMENT FOR SCOLE

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329

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ANALYTIC REDUNDANCY MANAGEMENT FOR SCOLE

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The objective of this work is to develop a practical sensor analytic redundancy management scheme for flexible spacecraft and to demonstrate it using the SCOLE experimental apparatus. The particular scheme to be used is taken from previous work on the Grid apparatus by Williams and Montgomery.

Reference:

Williams, J. P. and R. C. Montgomery: Failure Detection and Accommodation in Structural Dynamics Systems using Analytic Redundancy. 24th IEEE CDC, December 11-13, 1985.

## OBJECTIVE OF WORK

DEVELOP & TEST A PRACTICAL SENSOR ARM  
SCHEME USING SCOLE

## APPROACH

USE SCHEME PREVIOUSLY DEVELOPED FOR THE  
GRID BY WILLIAMS AND MONTGOMERY

330

## OUTLINE

The presentation is organized as follows: First, the scheme used by Williams and Montgomery is summarized. The scheme is based on a LQG design which is next described. Experimental results taken from the SCOLE apparatus on the performance of the Kalman filter of the LQG are presented and finally plans for completion of the work are given.

## OUTLINE

SUMMARIZE THE GRID SCHEME OF WILLIAMS AND MONTGOMERY

DESCRIPTION OF THE LQG DESIGN FOR THE SCHEME

RESULTS FROM THE SCOLE LAB EXPERIMENT

PLANS FOR COMPLETION OF THE WORK

## GRID ARM SCHEME - SUMMARY

The approach of Williams and Montgomery was to use a single active steady state Kalman filter which is designed for the estimated failure state in effect. Under the no-failure case the sensor residuals of this filter should be white with zero mean. The zero-mean character of the estimated residuals is monitored using Wald's sequential probability ratio test (SPRT). SPRT is a binary test to determine if a statistical variable is zero-mean or has a mean,  $m$ . As data samples are gathered a decision variable is monitored. It is initialized at zero and is sequentially modified by the data samples. If it crosses either of two decision thresholds a decision is made. One threshold corresponds to the zero-mean decision while the other is for the  $m$ -mean decision. A SPRT is run on each residual. If a decision of zero-mean is made the SPRT is reinitialized and run again. If a  $m$ -mean decision is made a failure is declared. In event of a declared failure the failure signature of the sensors in the residuals are examined to determine the failure state. A new LQG design for that failure state then replaces the current active design.

## GRID ARM SCHEME - SUMMARY

USE SINGLE, ON-LINE, KALMAN FILTER

USE SPRT TO CHECK THE ZERO MEAN CHARACTER  
OF THE ESTIMATED MEASUREMENT ERROR

IF FAILURE IS DETECTED, ISOLATE USING  
FAILURE SIGNATURE IN THE ESTIMATED  
MEASUREMENT ERRORS

## SCOLE ARM LQG DESIGN

The basis of the ARM to be used is the LQG. Therefore the first order of business is to develop a suitable LQG design wherein the modelling errors do not defeat the zero-mean character of the residuals. Most of the rest of the presentation concerns this design and its performance. For the design model we have used a 5-mode, modal model of SCOLE with the SCOLE platform fixed. Thus, there are no rigid body modes. Also the 5 modes selected are the five lowest frequency modes. Reaction jets are included in the filter but not in the regulator. The torque wheels on the other hand are used in both the filter and the regulator.

## SCOLE ARM LQG DESIGN

**DESIGN MODEL -- MODAL MODEL**

**FIXED SCOLE PLATFORM MODEL**

**NO RIGID BODY MODES**

**5 LOWEST FREQUENCY VIBRATION MODES**

**JETS INCLUDED IN FILTER, NOT IN REGULATOR**

**TORQUE WHEELS USED FOR THE REGULATOR**

## SCOLE CONFIGURATION

For the experiments reported herein and for the LQG design, the SCOLE platform rested on the ground and was considered fixed. We used the mid-mast and reflector accelerometers and the rate gyros on the mast tip. The actuators used were the reaction jets on the reflector and the torque wheels at the mast tip.

## SCOLE CONFIGURATION

### SCOLE PLATFORM FIXED

#### SENSORS --

MID-MAST AND REFLECTOR ACCELEROMETERS

RATE GYROS ON MAST TIP

#### ACTUATORS --

JETS ON REFLECTOR

TORQUE WHEELS AT MAST TIP

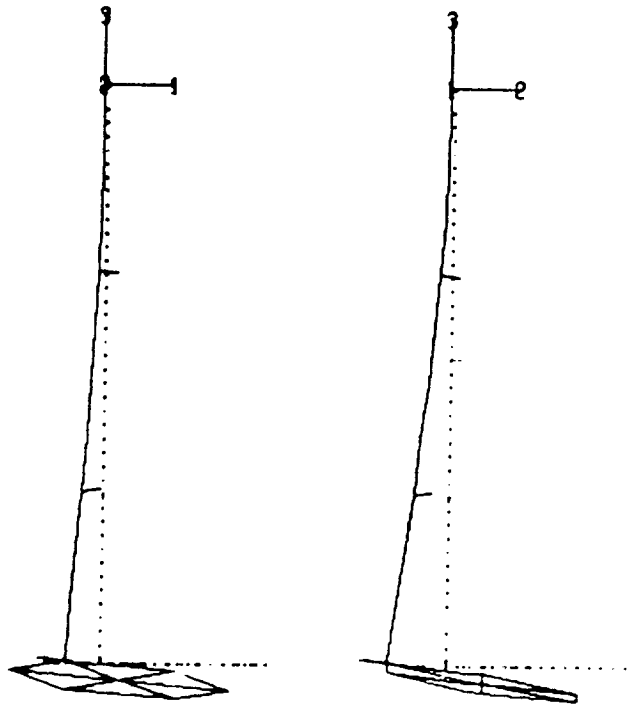
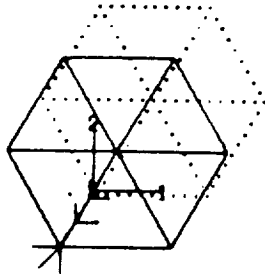
### SCALE MODEL AND TEST RESULTS

The next 10 slides are working charts organized in 5 pairs. They concern the 5 modes of the design model. The first chart of each pair contains the mode shape and frequency. This chart is followed by an experimental data record taken by manually exciting the structure at the natural frequency of the mode and taking free-decay data. The estimated mode amplitudes are indicated on the traces.

BRATIONAL MODE. FREQ (HZ)

. 4426 X10 + 0 0

10= 1 / 2 / 1



U(1). MAX=30.9375 IN-LBF

U(2). MAX=10.9375 IN-LBF

U(3). MAX=30.9375 IN-LBF



MODE 1 AMPLITUDE. MAX=.2



MODE 2 AMPLITUDE. MAX=.2



MODE 3 AMPLITUDE. MAX=.02

MODE 4 AMPLITUDE. MAX=.02

MODE 5 AMPLITUDE. MAX=.02

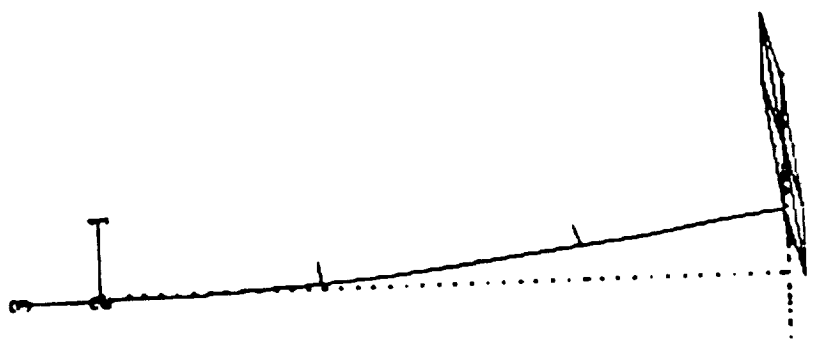
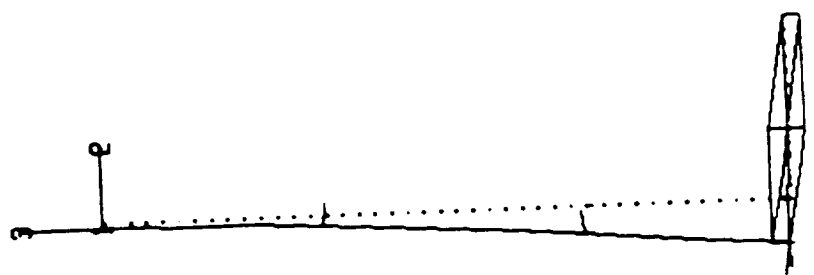
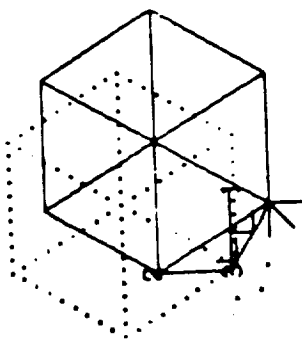
Mode 1.dat  
Mode 1 Free Decay 4



IO= 1 / 2 / 2

. 4466 X10 + 00

IRATIONAL MODE. FREQ ( HZ )



N-LBU(1). MAX=38.9375 IN-LBF

N-LBU(2). MAX=10.9375 IN-LBF

N-LBU(3). MAX=38.9375 IN-LBF



MAX= MODE 1 AMPLITUDE. MAX=.2



MAX=2MODE 2 AMPLITUDE. MAX=.2



MAX= MODE 3 AMPLITUDE. MAX=.02

MAX= MODE 4 AMPLITUDE. MAX=.02

Mode 2 c

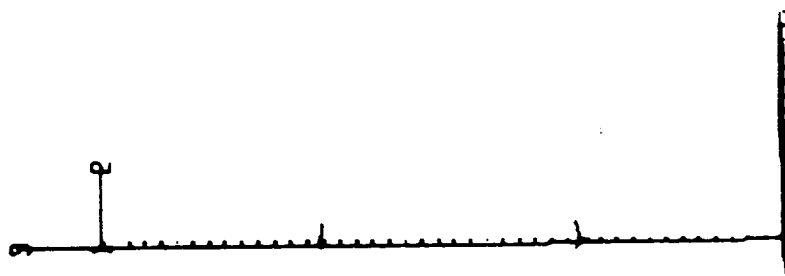
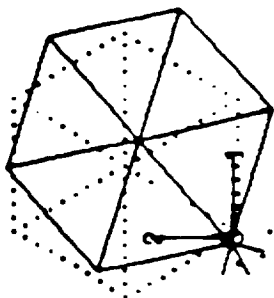
Mode 2 Free Decay

MAX= MODE 5 AMPLITUDE. MAX=.02

VIBRATIONAL MODE. FREQ (HZ)

. 1504 X10 ^ 0 1

ID= 1 / 2 / 3



1). MAX-30 9375 IN-LBF

2). MAX-10 9375 IN-LBF

3). MAX-30 9375 IN-LBF



MODE 3 AMPLITUDE, MAX= 02



MODE 4 AMPLITUDE, MAX= 02

Mode 3.dat

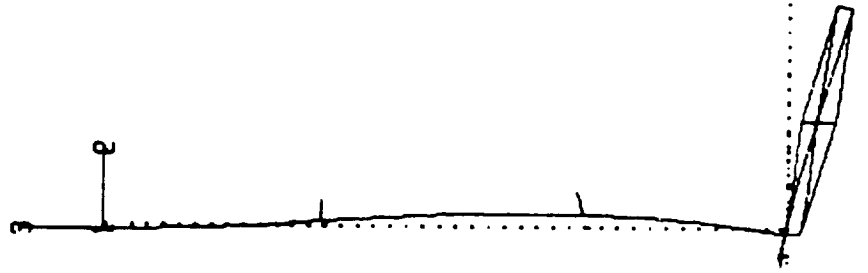
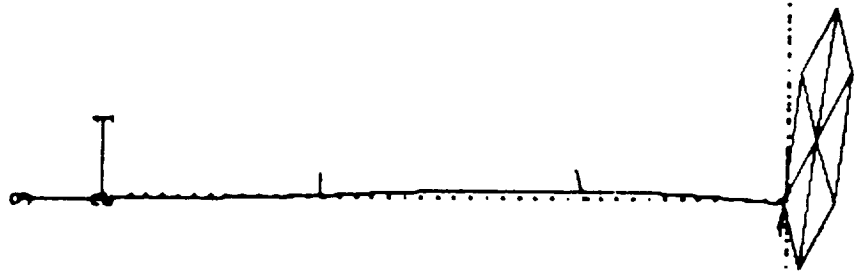
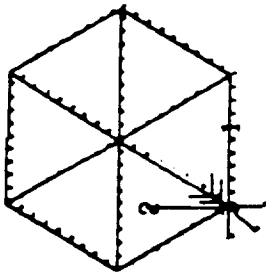
AMPLITUDE, MAX= 02

Mode 3 free-decay

RATIONAL MODE. FREQ (HZ)

. 2913 X10  $\rightarrow$  0.1

ID= 1 / 2 / 4



U(1). MAX-30.9375 IN-LBF

U(2). MAX-10.9375 IN-LBF

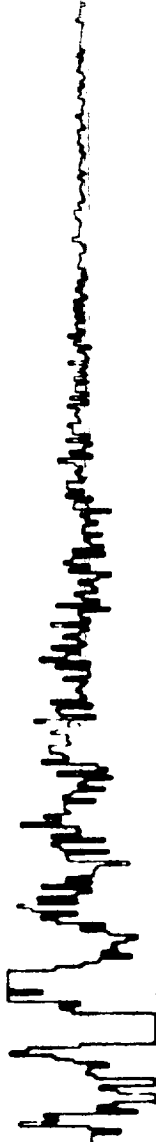
U(3). MAX-30.9375 IN-LBF



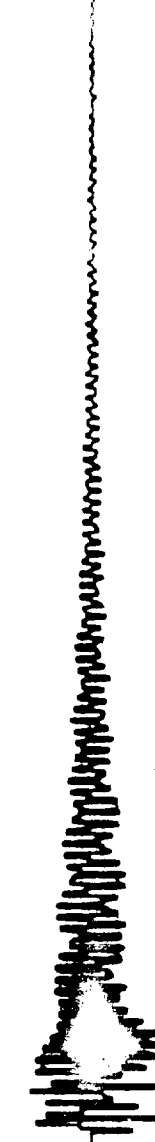
MODE 1 AMPLITUDE. MAX-.2



MODE 2 AMPLITUDE. MAX-.2



MODE 3 AMPLITUDE. MAX-.02



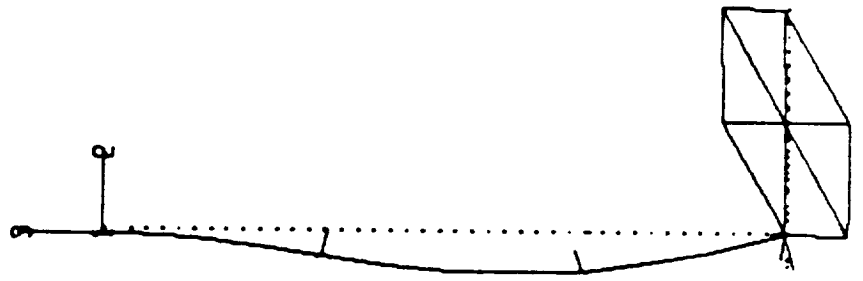
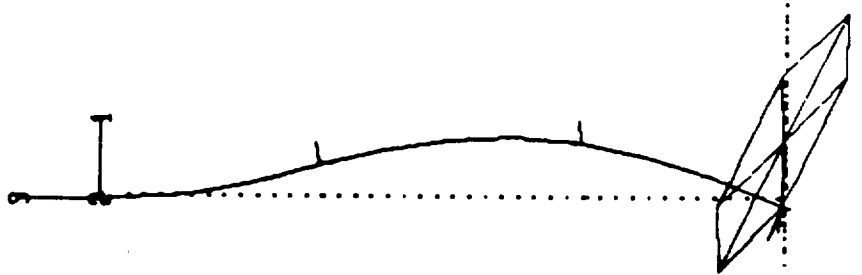
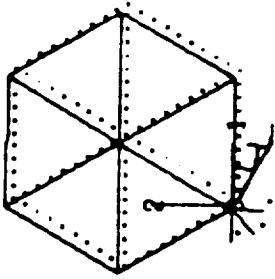
MODE 4 AMPLITUDE. MAX-.02



VIBRATIONAL MODE. FREQ (HZ)

. 4345 X10 + 01

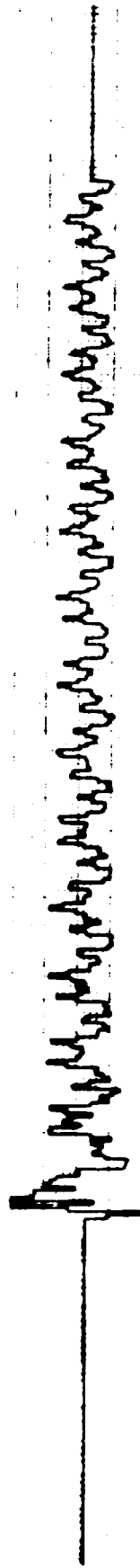
10= 1 / 2 / 5



U(1), MAX=30.9375 IN-LBF

U(2), MAX=10.9375 IN-LBF

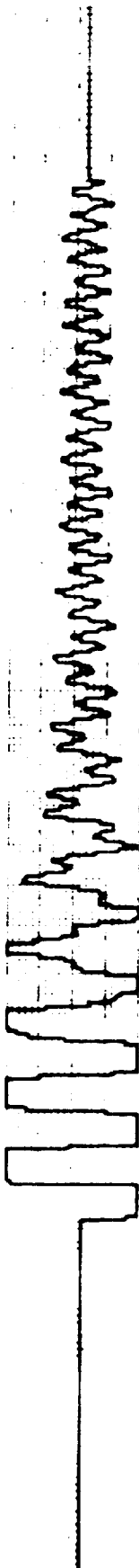
U(3), MAX=30.9375 IN-LBF



MODE 1 AMPLITUDE, MAX=.2



MODE 2 AMPLITUDE, MAX=.2



MODE 3 AMPLITUDE, MAX=.02



MODE 4 AMPLITUDE, MAX=.02



MODE 5 AMPLITUDE, MAX=.02

ftc

Mode 5 free decay



## FUTURE PLANS

Tasks that remain to be accomplished are the complete validation of the Kalman filter and regulator for both free-decay and forced response. The SPRT must be tested on this nominal filter design and thresholds need to be set to avoid false alarms in light of the modelling errors inherent in the design. Possible sources of the modelling errors are excitation of modes not modelled and higher order and nonlinearities in the description of the sensors and actuators. The next step is to select several failure cases for the ARM and generate appropriate LOG designs for each of these. Then the ARM performance can be evaluated. Current plans call for this to be completed by mid June 1988. This schedule is ambitious and may slip because of NASA revectoring of resources.

## FUTURE PLANS

VALIDATE NOMINAL KALMAN FILTER

TEST SPRT ON NOMINAL

DESIGN FOR NULL FAILURES OF SENSORS

VALIDATE FAILURE CASE DESIGNS

TEST OVERALL ARM FDI PERFORMANCE

TO BE COMPLETED BY BY MID JUNE '88

346