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N-ROSS: THE DYNAMICS AND CONTROL ISSUES

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MISSION AND APPROACH

The Navy Remote Ocean Sensing System (N-ROSS) satellite will be launched in 1990 to provide the Navy with the operational capability to measure sea surface parameters on a worldwide year-round basis in all weather conditions. The satellite will carry four primary instruments, two active and two passive, in a low-earth sun-synchronous orbit. The radar altimeter, similar to the instrument currently flying on GEOSAT, will measure absolute altitude above the geoid and will contribute to the determination of wave height. The scatterometer, an evolutionary design derivative of the SEASAT instrument, will be capable of both wind speed and wind direction measurement. The microwave imager (or SSM/I) and the Low Frequency Microwave Radiometer are passive scanning instruments, the first operating at 19.3, 22.2, 37.0 and 85.5 GHz, and the second at 5.2 and 10.4 GHz. The SSM/I, currently under development for the DMSP program, will measure water vapor and map sea ice edges. The LFMR is a new instrument design that will measure sea surface temperature to better than 1^{o}C, to contribute to the mapping of currents, fronts and eddies in the ocean surface structure.

THE N-ROSS SATELLITE MISSION:

MEASURE SEA SURFACE PARAMETERS OVER 95% OR MORE OF THE WORLD'S OCEANS UNDER ALL WEATHER CONDITIONS

THE APPROACH:

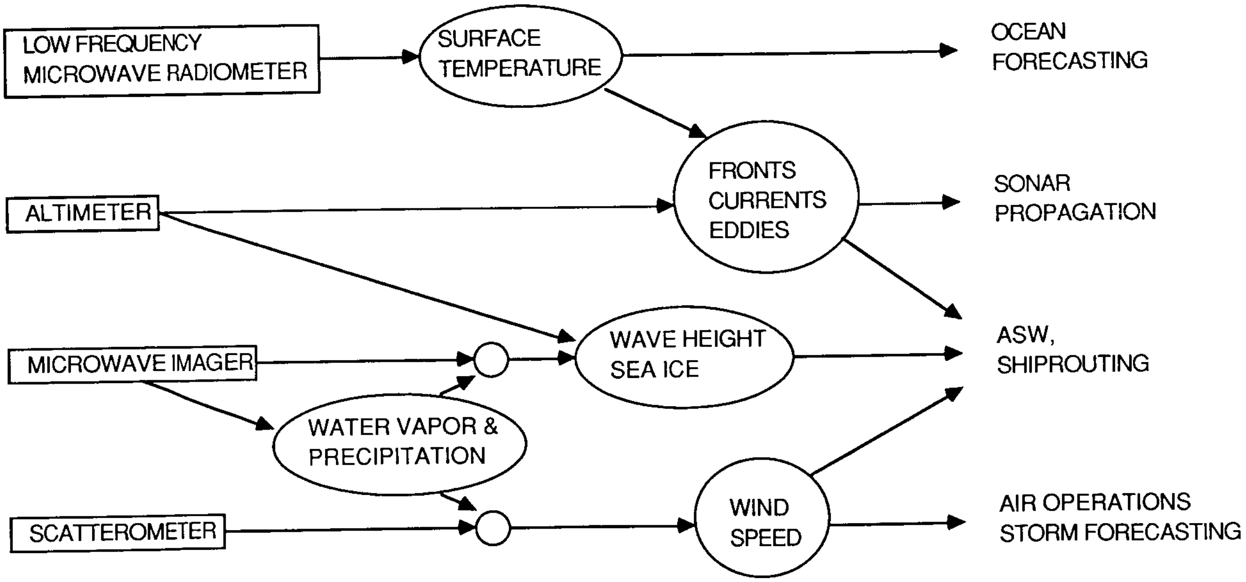


Figure 1

BASELINE N-ROSS CONFIGURATION

To evaluate the feasibility of the N-ROSS mission, a baseline vehicle design was developed during 1984 and 1985 as a derivative of the DMSP satellite design. An end view of this design, shown in Fig. 2, includes a fixed solar array attached to the far end, the SSM/I mounted on the top of the main structure, the altimeter (and a Doppler beacon antenna) on the bottom or earth-facing surface, and the scatterometer antennas to the right of the main structure. Clearly the most mechanically complex instrument is the LFMR, incorporating a nearly 22 ft. deployable truss structure (DTS) antenna, two deployed support booms and a radiometer electronics package all spinning at 15.8 rpm. The spin drive motor is mounted at the outboard end of an 8 ft. deployed spacecraft boom, required to provide non-interfering fields-of-view for all four sensors on the three-axis-stabilized vehicle.

NROSS/LFMR
BASELINE CONFIGURATION (DEPLOYED)

- **Mechanical coupling of reflector/feed synchronization**

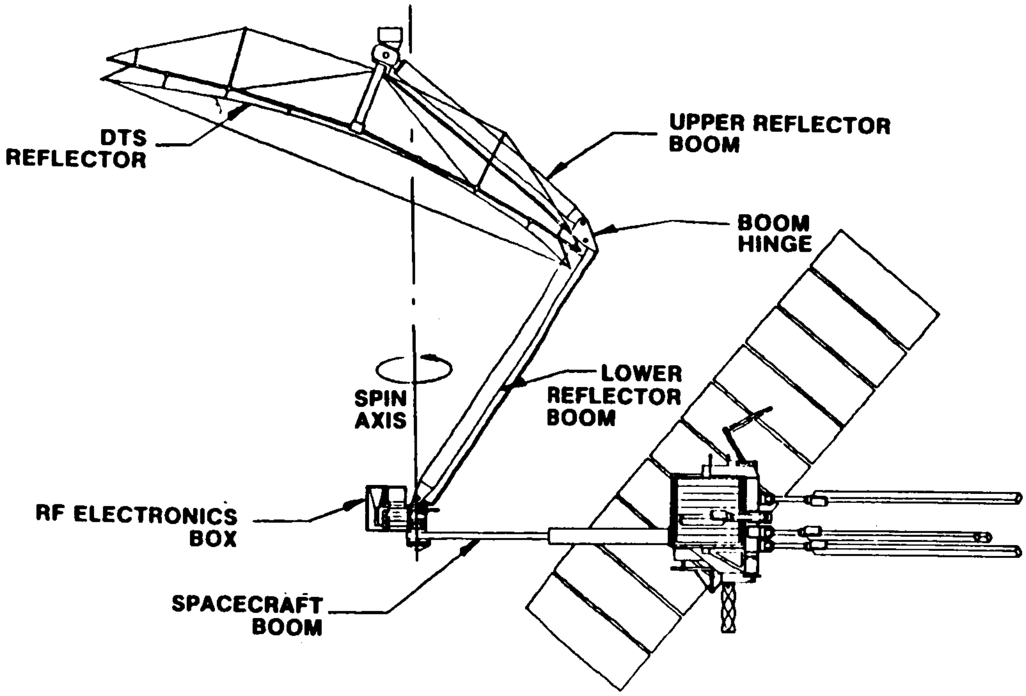


Figure 2

DYNAMICS AND CONTROL CONCERNS

The flexibility of the LFMR and the other appendage structures, together with the active spin drive system and the 0.05 deg pointing knowledge requirement for the LFMR sensor boresight, combine to immediately identify control-structure interaction as a technology issue in the N-ROSS baseline design. Figure 3 highlights some fundamental concerns involving the dynamics and control performance of flexible satellites. These issues are common to most satellite concepts incorporating large lightweight flexible components, even those which do not spin, and they were considered significant in the baseline N-ROSS design.

FUNDAMENTAL CONCERNS WITH THE DYNAMICS AND CONTROL OF FLEXIBLE SPACECRAFT

MOTION OF THE FLEXIBLE STRUCTURES CAN DESTABILIZE ATTITUDE CONTROL SYSTEM

ATTITUDE CONTROL SYSTEM CAN EXCITE STRUCTURAL RESONANCES

EXTERNAL DISTURBANCES CAN EXCITE STRUCTURAL RESONANCES

STRUCTURAL FLEXIBILITY ALONG WITH INHERENT ERROR SOURCES CAN DEGRADE POINTING PERFORMANCE BEYOND THE SPECIFIED VALUE

Figure 3

ADDITIONAL N-ROSS ISSUES

The design and concept of operations for the baseline N-ROSS design raises several specific issues, related to control-structure interaction, but not typically addressed in the development of technologies for the control of large space structures. While the LFMR is designed to operate at a constant spin rate, the initial spin up (and contingency despin) of the sensor raises concern that it might act as a frequency sweep disturbance input to the spacecraft, with the potential to excite structural resonances up to 0.26 Hz (15.8 rpm). Additionally, the LFMR antenna and support booms are expected to deform measurably under centrifugal forces when spinning (which is taken into account in the design, so that the deformed configuration has the desired geometry). The deformation will result in a change in mass properties, thereby inducing both a static and a dynamic imbalance. This then is expected to lead to a requirement for an on-orbit balance mechanism. Finally, the momentum of the LFMR and the SSM/I are each proposed to be compensated by a separate momentum wheel controlled independent of the reaction-wheel-based attitude control system. These separate control loops, all coupled through the vehicle rigid body dynamics, can lead to a system which cannot be guaranteed to be stable for all inputs.

ADDITIONAL CONCERNS SPECIFIC TO N-ROSS

SPIN-UP OPERATIONS MAY SWEEP STRUCTURAL RESONANCES

LFMR MAY REQUIRE ON-ORBIT BALANCE TO COMPENSATE FOR STATIC DEFLECTIONS UNDER SPIN

MOMENTUM COMPENSATION REQUIRES SEPARATE CONTROL LOOP

Figure 4

DYNAMICS AND CONTROL CONTRIBUTORS

Many aspects of the N-ROSS baseline design have the potential to contribute to a control-structure interaction problem for this vehicle. Figure 5 summarizes the most significant of these. They include interacting flexible structures and rotating instruments and devices on the vehicle, independently designed and implemented control systems that are coupled through either vehicle dynamics or structural dynamics, and external disturbances that have the potential to degrade pointing performance and even destabilize the attitude of the satellite.

CONTRIBUTING SOURCES

FLEXIBLE STRUCTURES

- LFMR Reflector and Booms
- LFMR Deployment Boom
- NSCAT Antennas
- Solar Array

ROTATING COMPONENTS

- LFMR
- SSM/I
- Momentum Compensation Assemblies
- Reaction Wheels

CONTROL SYSTEMS

- Attitude Control
- LFMR Drive System
- SSM/I Drive System
- MCA Drives

OTHER DYNAMICS

- Thruster firing
- Deployment sequences
- External torques

Figure 5

STATIC AND DYNAMIC BALANCE

The static and dynamic balance of a deformable spinning instrument such as the LFMR warrants special examination. In balancing a rigid spinning device (such as the SSM/I), the static and dynamic balance can be performed sequentially. In a nonspinning state, the center of mass can be adjusted to lie on the spin axis. The dynamic balance can then be achieved by spinning the sensor, and symmetrically adjusting ballast mass to eliminate (or reduce) the cross-products of inertia with respect to the spin axis. For the SSM/I, this will be accomplished in ground test prior to integration with the satellite.

For an asymmetric flexible structure such as the LFMR, the center of mass and inertias of the structure will change with spin rate, and the alignment of both the center of mass and the principal inertia axis can only be accomplished after the instrument is spinning. These same mass properties also vary between a one-g and a zero-g environment, and between atmosphere and vacuum. This leads to a requirement for either extensive testing coupled with simulation to extrapolate to on-orbit conditions, or an active method of achieving instrument balance once the vehicle is in orbit.

FOR A RIGID STRUCTURE

STATIC - PLACE C.G. ON THE SPIN AXIS

DYNAMIC - ALIGN THE PRINCIPAL INERTIA AXIS WITH SPIN AXIS

FOR A FLEXIBLE STRUCTURE

C.G. AND INERTIA AXES WILL MOVE AS INSTRUMENT IS SPUN UP

BOTH "STATIC" AND "DYNAMIC" BALANCE MUST BE ACHIEVED AT FULL SPIN RATE

Figure 6

DYNAMIC STABILITY STUDY

In response to the recognition that control structure interaction was a technology driver for the N-ROSS baseline satellite design, the Naval Research Laboratory was commissioned in September 1985 to lead a six month effort to evaluate the N-ROSS/LFMR configuration. A Dynamic Stability Study would focus on the baseline configuration, assuming a design frozen to that detailed in the April 1985 conceptual design review. The study objectives are recounted in Fig. 7.

OBJECTIVES:

- DEVELOP INTEGRATED FLEXIBLE BODY STRUCTURAL DYNAMICS AND CONTROL SIMULATION OF THE ON-ORBIT N-ROSS CONFIGURATION
- DETERMINE ATTITUDE STABILITY IN SPIN-UP AND STEADY-STATE OPERATION OF THE LFMR
- ASSESS THE CONTRIBUTION OF STRUCTURE AND CONTROL INTERACTIONS TO LFMR BORESIGHT POINTING
- EXAMINE OFF-NOMINAL CONDITIONS TO DETERMINE CONTROL MARGINS AND PARAMETER SENSITIVITIES INHERENT IN THE BASELINE DESIGN

Figure 7

DYNAMIC STABILITY STUDY PARTICIPANTS

The original organization of the study called for two independent teams of investigators, using software tools and simulation techniques of their own choosing but considering a common design database, to each assemble an integrated simulation capable of addressing the four study objectives. The original teaming arrangements paired RCA with Aerospace Corp. and Harris with Cambridge Research. During the course of the study the government announced its intention to competitively procure the N-ROSS satellite; at that point Harris and RCA chose to voluntarily cease further participation in the study. Using control system and structural models previously developed by these two participants, the two remaining team members continued to develop the integrated simulations. The MULTIFLEX code was developed internally at Aerospace for this purpose, while Cambridge Research employed the DISCOS code originally developed at Martin Marietta for NASA Goddard Space Flight Center.

RCA ASTROELECTRONICS

Provided vehicle structural models

Provided attitude control system model

HARRIS GASD

Provided LFMR structural model

Provided drive motor and MCA control models

AEROSPACE CORP.

Developed integrated simulation using MULTIFLEX

CAMBRIDGE RESEARCH

Developed integrated simulation using DISCOS

Figure 8

COMMON ASSUMPTIONS AND GROUND RULES

The two remaining study participants continued their work independently, with the Naval Research Laboratory maintaining a common and consistent set of model data to be used by both parties. NRL also provided resolution of modeling issues raised by the participants and defined the scope and limitations of the simulations and analyses to be performed.

Figure 9 lists the principal modeling assumptions. The number of structural modes included for each of the flexible components, together with the total number of states in the simulation, are listed to the right. These are taken from the Aerospace simulation; Cambridge Research employed two models - the first with 63 states modeled only the LFMR as flexible, the second included all flexible appendages and contained 109 states.

	(modes included)
Rigid spacecraft bus	
Detailed attitude determination and control subsystem model - reaction wheel control loops, sensor dynamics, etc	
Flexible scatterometer antenna model	6 modes
Flexible LFMR support boom models	2 modes
Flexible LFMR antenna model	5 modes
LFMR momentum compensation assembly model	
Fixed flexible solar array model	5 modes
Fixed rigid SSM/I model	
Orbital pitch rate included in dynamics	
	51 vehicle states
	15 control states
	66 total states

Figure 9

FREQUENCY CHARACTERISTICS

The frequency characteristics of the April 1985 baseline design are summarized in Fig. 10. The most significant concerns, and those which received careful examination during the course of the study, were the coupling of the LFMR spin frequency and the lower solar array modes with the attitude control loop, specifically the digital filter. Since the spin rate is well below the vehicle rate determination sampling frequency, it was anticipated as well that an imbalance of the LFMR would be observable as an attitude disturbance by the attitude determination software.

CONTROL/STRUCTURES FREQUENCY CHARACTERISTICS

ACS BANDWIDTHS

GYRO	F < 2.244 HZ
DIGITAL FILTER	F < 0.5 HZ
RATE DETERMINATION SOFTWARE	F < 5 HZ
REACTION WHEEL	F > 0.000265 HZ

SYSTEM MODE FREQUENCIES

LFMR SPIN RATE	0.26 HZ
SOLAR ARRAY MODE FREQS.	0.397, 0.576, 0.723, 1.08, 1.37
LFMR MODE FREQS.	1.67, 1.89, 2.72, 5.03, 6.05
SCATTEROMETER MODE FREQS.	4.98, 5.08, 36.5, 43.9, 75.4
SUPPORT BOOM MODE FREQS.	14.1, 15.1

Figure 10

ISSUES CONSIDERED

The development of extensive integrated control-structure simulations provided the opportunity to examine a wide range of issues of concern in the baseline design. The list of issues examined, summarized in Fig. 11, attests to the capacity of such simulations to go far beyond the relatively straightforward task of demonstrating stability and determining overall steady-state structure and control performance. Such simulations can be used effectively to refine the design for a particular concept. Results of the N-ROSS simulations led directly to recommendations for revised LFMR imbalance specifications and improved values for attitude control subsystem loop gains.

INDIVIDUAL ISSUES EXAMINED USING INTEGRATED SIMULATIONS

STEADY - STATE VEHICLE AND SENSOR POINTING PERFORMANCE

EFFECT OF STATIC AND DYNAMIC IMBALANCE ON ATTITUDE STABILITY

EFFECT OF SPIN RATE ON STATIC AND DYNAMIC IMBALANCE

SENSITIVITY OF BALANCE TO BALANCE WEIGHT MOVEMENT

LFMR, SCATTEROMETER AND SOLAR ARRAY DEFORMATION

MOMENTUM MISMATCH EFFECTS

SPIN AXIS MISALIGNMENT EFFECTS

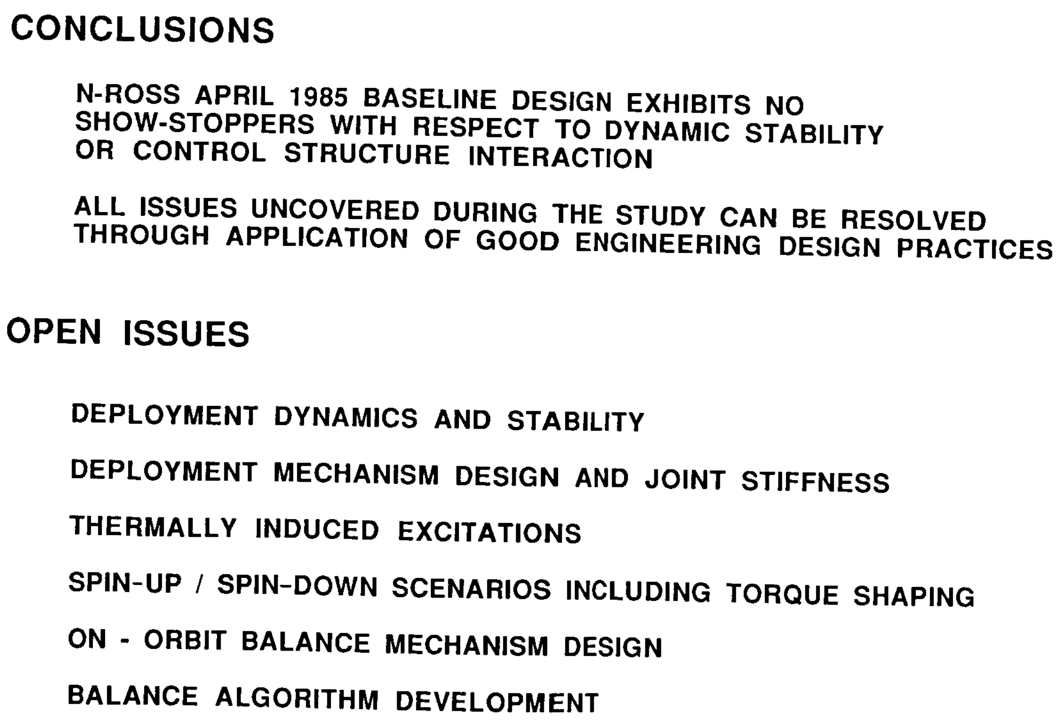
THRUSTER DISTURBANCE EFFECTS

SPIN-UP DYNAMIC PERFORMANCE

Figure 11

CONCLUSIONS AND OPEN ISSUES

As a result of these efforts, the N-ROSS Dynamic Stability Study team concluded by consensus that the frozen April 1985 design was viable and contained no "show stoppers", although it was also clear from the study results that the configuration required further optimization. While the frozen N-ROSS configuration used has since been superceded, and the vehicle is now under competitive procurement, several other results remain from the study that will have lasting value to the N-ROSS program. The importance of constructing an integrated simulation, to serve as a design and verification aid, has been clearly established. The two team approach to the study afforded the Navy a higher degree of confidence in the results than could have been accomplished by a single simulation, and the approach led to results that highlighted subtleties in the model and simulation development that surely would have been overlooked without the benefit of an independent companion simulation with which to compare.



CONCLUSIONS

N-ROSS APRIL 1985 BASELINE DESIGN EXHIBITS NO SHOW-STOPPERS WITH RESPECT TO DYNAMIC STABILITY OR CONTROL STRUCTURE INTERACTION

ALL ISSUES UNCOVERED DURING THE STUDY CAN BE RESOLVED THROUGH APPLICATION OF GOOD ENGINEERING DESIGN PRACTICES

OPEN ISSUES

DEPLOYMENT DYNAMICS AND STABILITY

DEPLOYMENT MECHANISM DESIGN AND JOINT STIFFNESS

THERMALLY INDUCED EXCITATIONS

SPIN-UP / SPIN-DOWN SCENARIOS INCLUDING TORQUE SHAPING

ON - ORBIT BALANCE MECHANISM DESIGN

BALANCE ALGORITHM DEVELOPMENT

Figure 12

ACKNOWLEDGEMENTS

Some of the material presented here is excerpted from the final reports of the studies conducted by Aerospace Corp. and Cambridge Research Division of Photon Research Associates. The authors of those reports are: at Aerospace - P. Mak, M. Tong, A. Jenkin and A. Compito, and at Cambridge Research - J. Turner, H. Chun, and K. Soosaar. S. Fisher of NRL maintained the database models for the study. F. Diederich commissioned the study and provided general guidance.