SHUTTLE FLIGHT CONTROL
AND STRUCTURE INTERACTION

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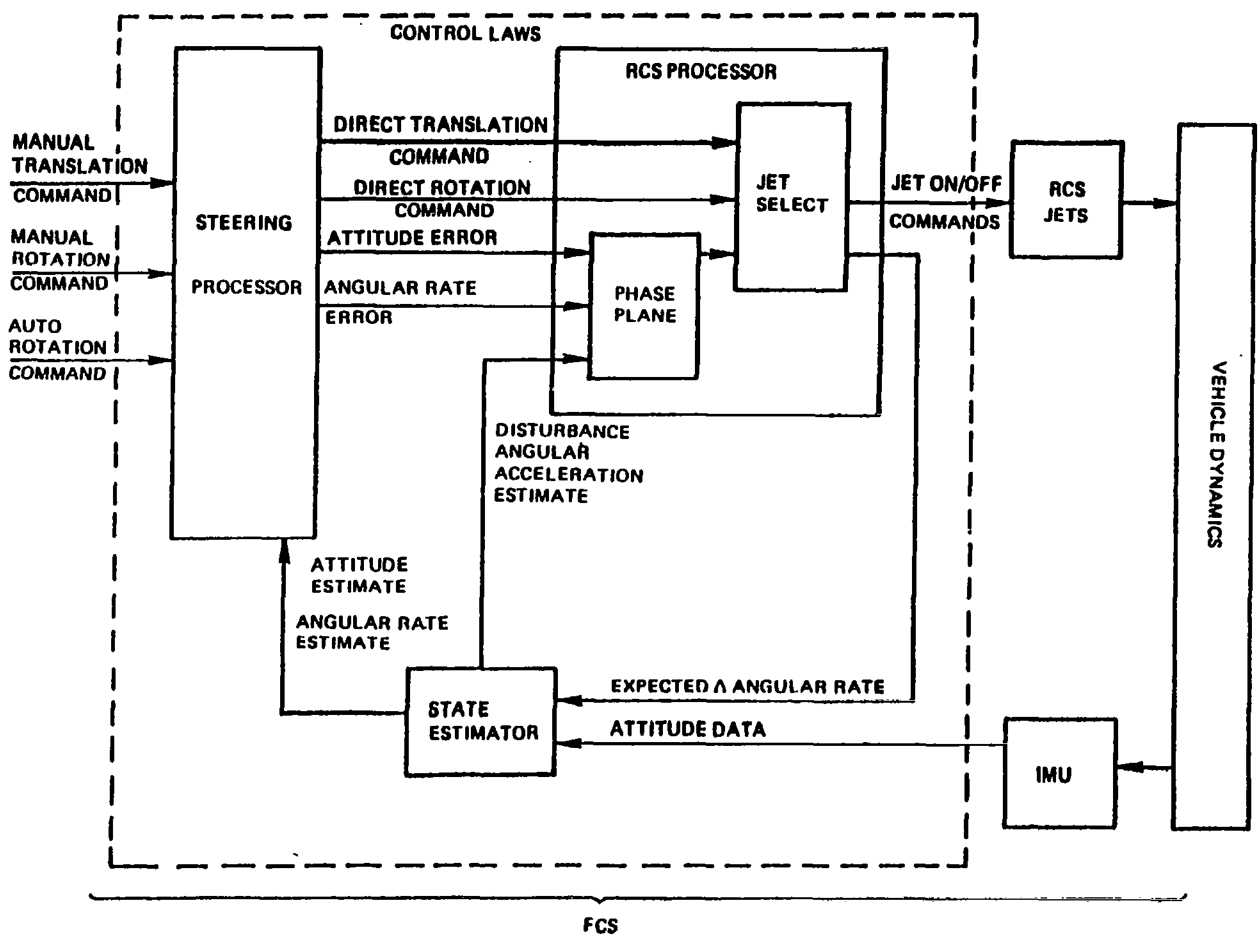
- A brief overview of the DAP
- Results of the dynamic interaction study of the Orbiter with the General Dynamics Beam attached
- Preliminary results of the three degree of freedom payload parametric study

This is a diagram of the Orbiter Flight Control System (FCS). The functions relating only to the OMS have been eliminated for clarity. The vehicle can be maneuvered either manually or automatically. To perform an automatic maneuver the pilot specifies a new orientation for the Orbiter. This is processed by the steering processor, which sends a corresponding attitude error to the RCS processor. Jets are commanded to fire to reduce this error. The jet firings produce attitude changes that are measured by the IMU and sent to the state estimator at 6.25 Hz. The state estimator produces rate and acceleration estimates, filtering out high-frequency oscillations. The steering processor produces a new rate and attitude error from this data.



Characteristics of the Orbiter and DAP

Orbiter

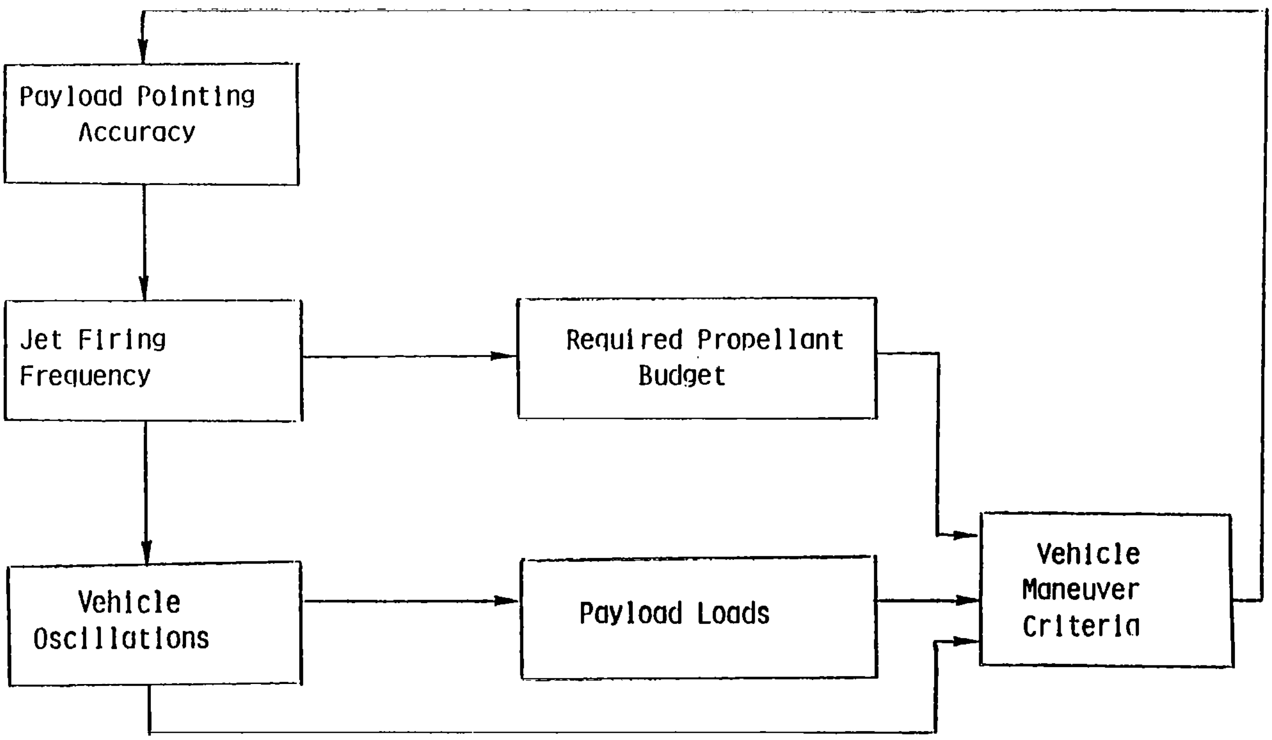
- Low inertial cross coupling
- First bending frequency 0.431 Hz
- Large RCS jet coupling particularly roll to yaw
- I_{xx} = .883x10^6 slug-ft^2, 12.5% of I_{zz}
- Operational maneuver rate limit of 2 °/sec

DAP

- Phase Plane autopilot assuming decoupled axis
- State Estimator uses IMU data only
    - second order filter characteristic
    - 6 dB down at .06 Hz with vernier gains
- Designed assuming a rigid vehicle

This flow chart maps the interrelation of different criteria for the Orbiter flight envelope. The three parameters that are used to define an envelope are payload pointing accuracy, propellant budget and payload loads. While often considered independently, they affect one another as indicated in the block diagram.

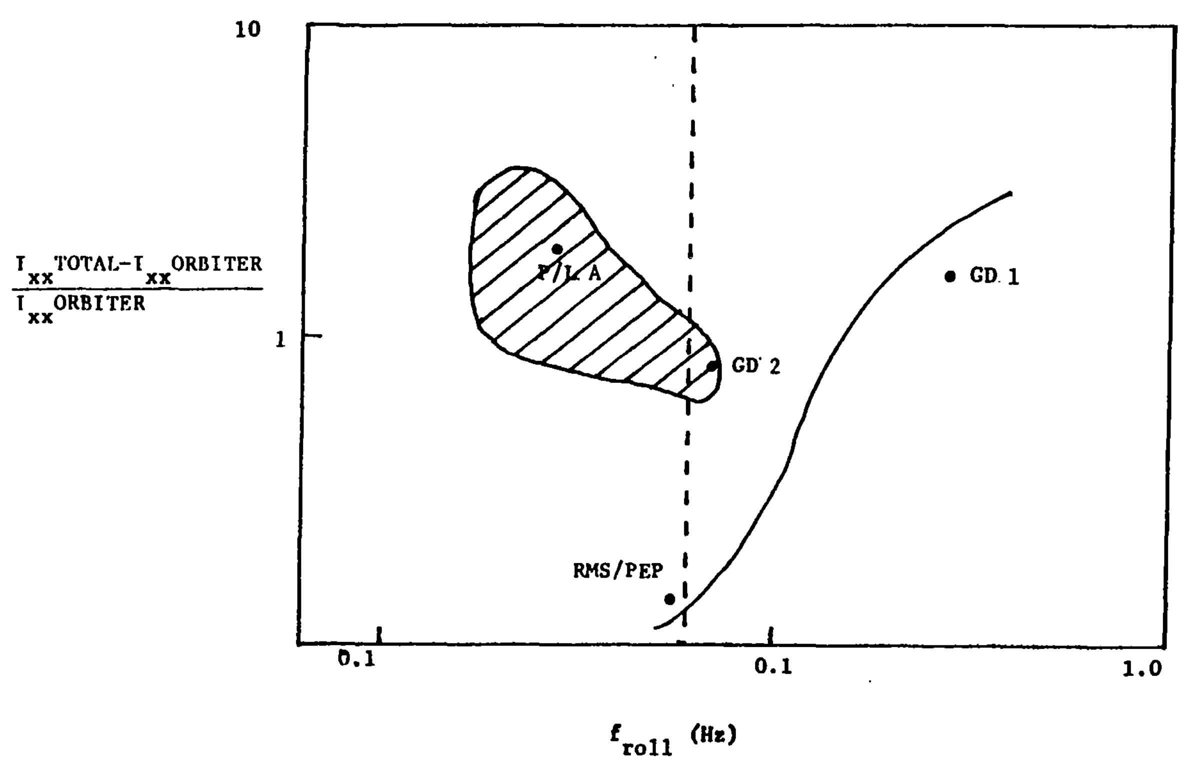
Definition of the Orbiter Flight Envelope



Classes of System Response for the Orbiter with a Flexible Payload

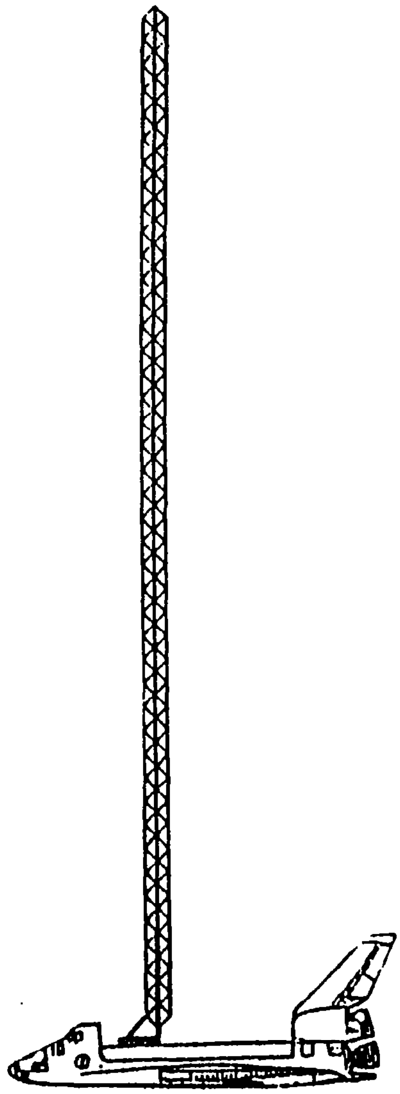
1. The Autopilot does not respond to the payload oscillations
   - vehicle oscillations small
   - payload oscillations may be large
2. The Autopilot responds to payload oscillations
   - vehicle rate or attitude errors exceed set limits
   - vehicle oscillations may diverge
   - attitude excursions may be small

This graph defines the regions of autopilot interaction for the Orbiter with a flexible payload. The x axis is the roll fundamental frequency and the y axis is the ratio of payload roll inertia to empty Orbiter roll inertia. Little or no interaction occurs in the region to the right of the solid line. In the region to the left some closed-loop response has been observed. The dotted line indicates the state estimator 6 dB point. The ruled region is the current area of interest for the parametric study of the DAP response.



Summary of results of the dynamic interaction analysis of the General Dynamics beam

The Orbiter with the General Dynamics beam experiment is pictured here.



This table gives the results of the dynamic interaction analysis of the Orbiter/GS beam combination. The columns list the maneuver performed, the fuel expended, the type of Orbiter and payload oscillations, whether the DAP sent oscillatory firing commands to the jets, and comments.

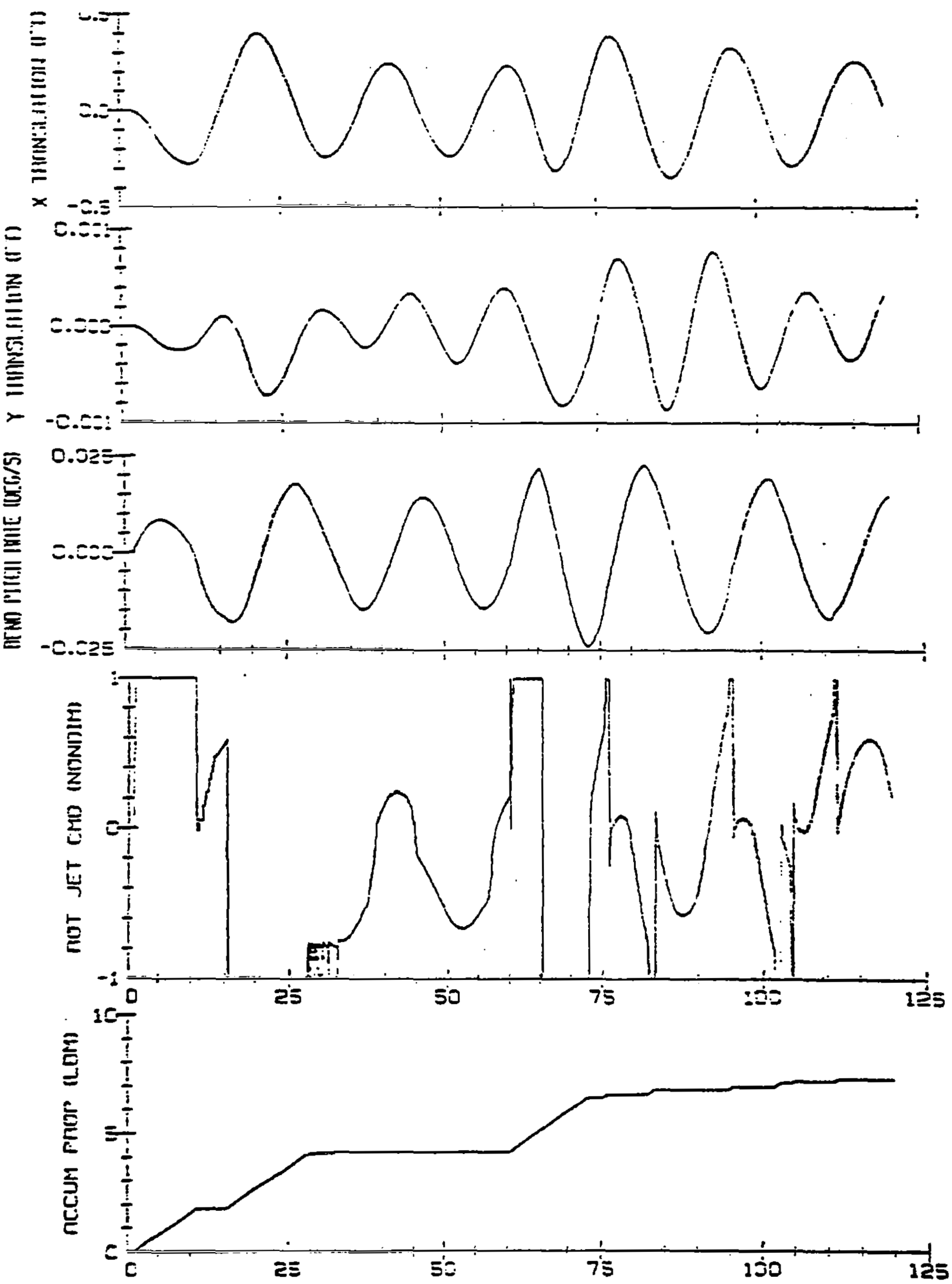
Except for the 5° roll case with rate limit clampdown, the vehicle and payload remained stable. In cases 4 and 7 through 10 oscillatory commands were sent to the jets indicating vibration feedback. Note that 4 was the worst case. Case no. 8 is worse than case no. 1, but case no. 10 is not worse than no. 4, as might be expected.

DYNAMIC INTERACTION STUDY SUMMARY

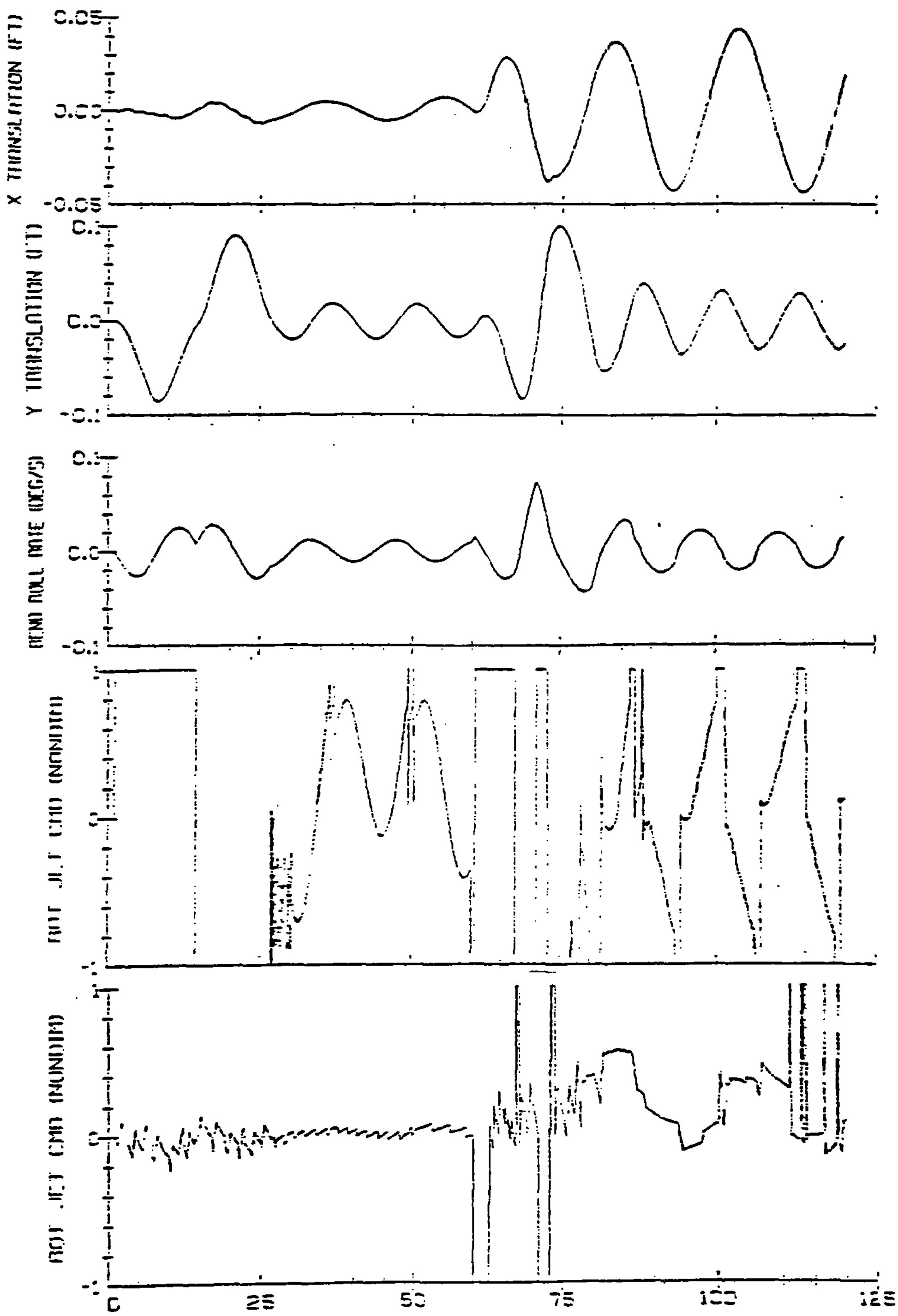
[Fundamental frequency in pitch = 0.046 Hz]

	Maneuver	Fuel	Oscillations			comments
			Payload	Vehicle	ROT-JET-CMD	
1	5° Roll	6.1	stable	stable		
2	Pitch	4.2	stable	stable		
3	Yaw	6.3	stable	stable		
4	5° Roll with att. hold RL=.01, DB=.1	12.0	diverge	diverge	roll,pitch	results after clampdown
5	Astronaut Forced Osc.	-	stable	stable		results after autopilot on
6	Jet F3U Stuck on	-	stable	stable		
7	Jet R4U Stuck on	-	stable	stable	yaw	
8	3.2° Roll Rate =.2	6.1	stable	stable	roll up to 60 sec	.046 Hz pulse
9	5° Pitch with att. hold	7.5	stable	stable	pitch	
10	3.2° Roll with att. hold	10.5	stable	stable	roll until clampdown	

This figure and the next one are examples of the output from two SLS runs. Note that in both cases oscillatory commands are being sent to the jets, but only in the roll case are diverging oscillations seen.



5 deg pitch with rl = .02 deg/sec, db = 1 deg with an attitude hold at 60 sec with rl = .01 deg/sec, db = 1 deg



5 deg roll with rl = .02 deg/sec, db = 1 deg with an attitude hold at 60 sec with rl = .01 deg/sec, db = 1 deg

The Three Degree of Freedom Payload Simulation for Orbiter/Payload Parametric Studies

The General Dynamics Beam

- Base Properties
  - I_{xx} payload/I_{xx} vehicle = .698
  - f_{roll} .0642 Hz
    f_{pitch} .049 Hz
    f_{yaw} .667 Hz
- Results with base model
  - payload diverges in pitch
  - oscillatory jet firings after rate limit change
- Trends with parameter changes
  - vehicle oscillations are greatest at f_{roll} = .046 Hz
  - behavior insensitive to yaw frequency and I_{zz} payload changes
  - increasing rate limits and deadbands can limit small oscillations
  - vehicle oscillations increase as payload inertia increases

The last four figures give results from the parametric study. The first case is for a three-degree-of-freedom model of the GD beam. The second is for a payload with a roll bending frequency of 0.02 Hz and a larger inertia ratio. In the latter case a more severe oscillatory rotation command is seen and the vehicle maneuvering is more sluggish.

5° Roll Maneuver

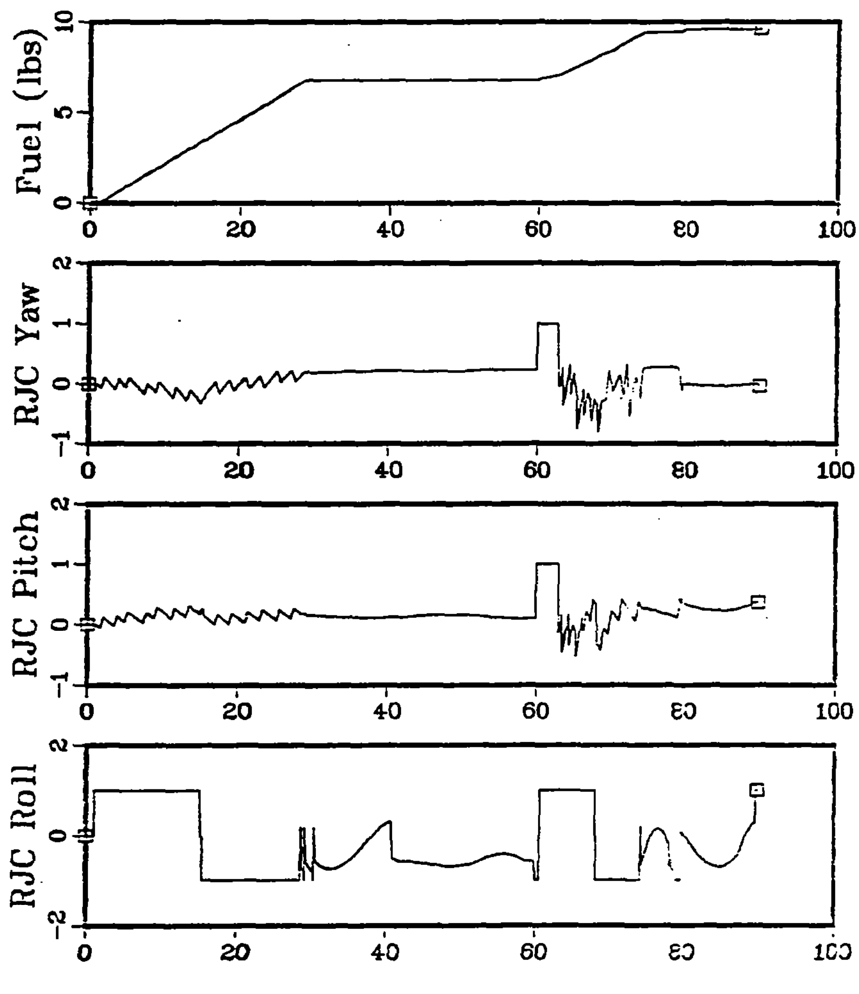
rl = .02 °/sec , db = .5°

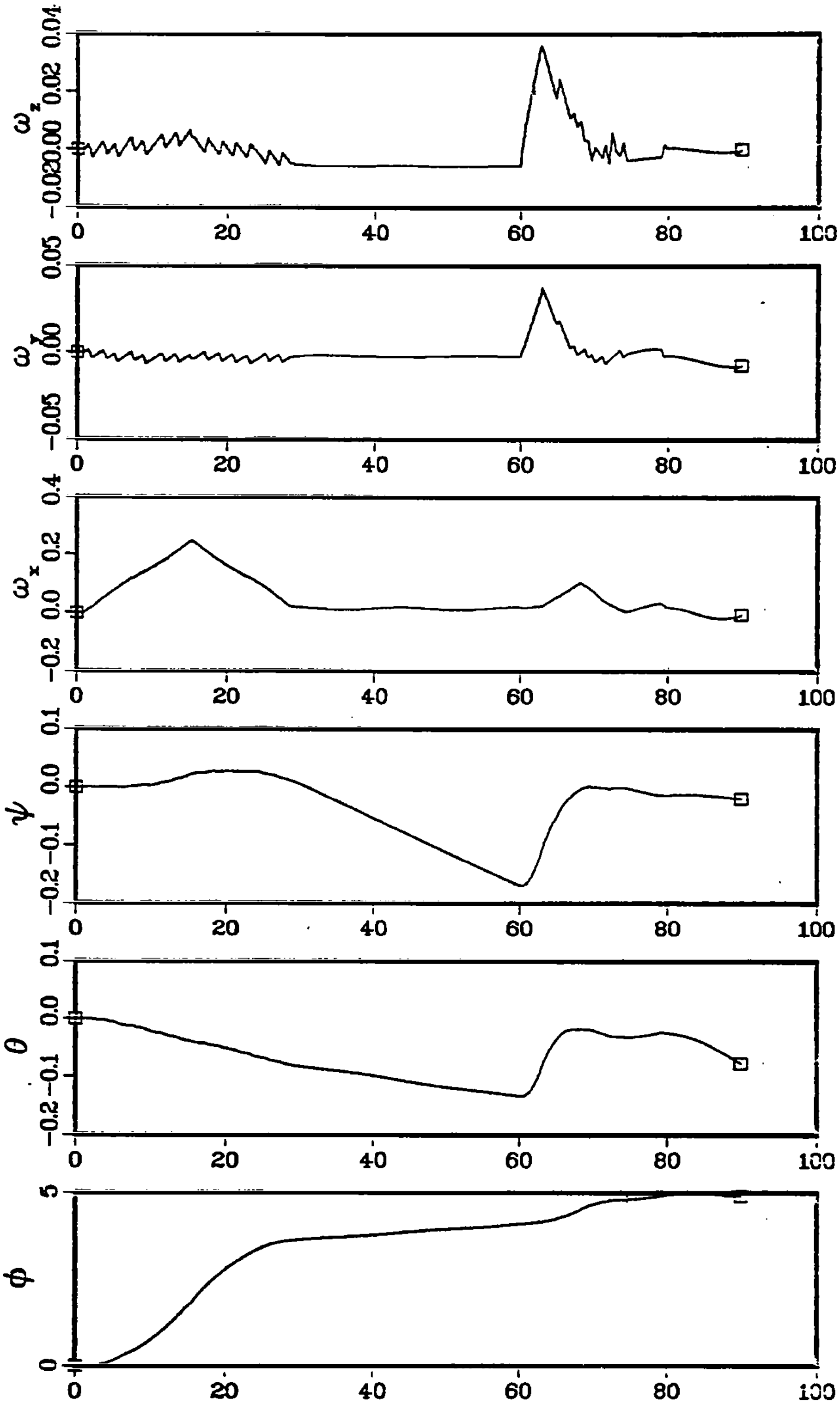
at 60 sec set

rl = .01 °/sec , db = .1°

with

General Dynamics Beam as the Payload





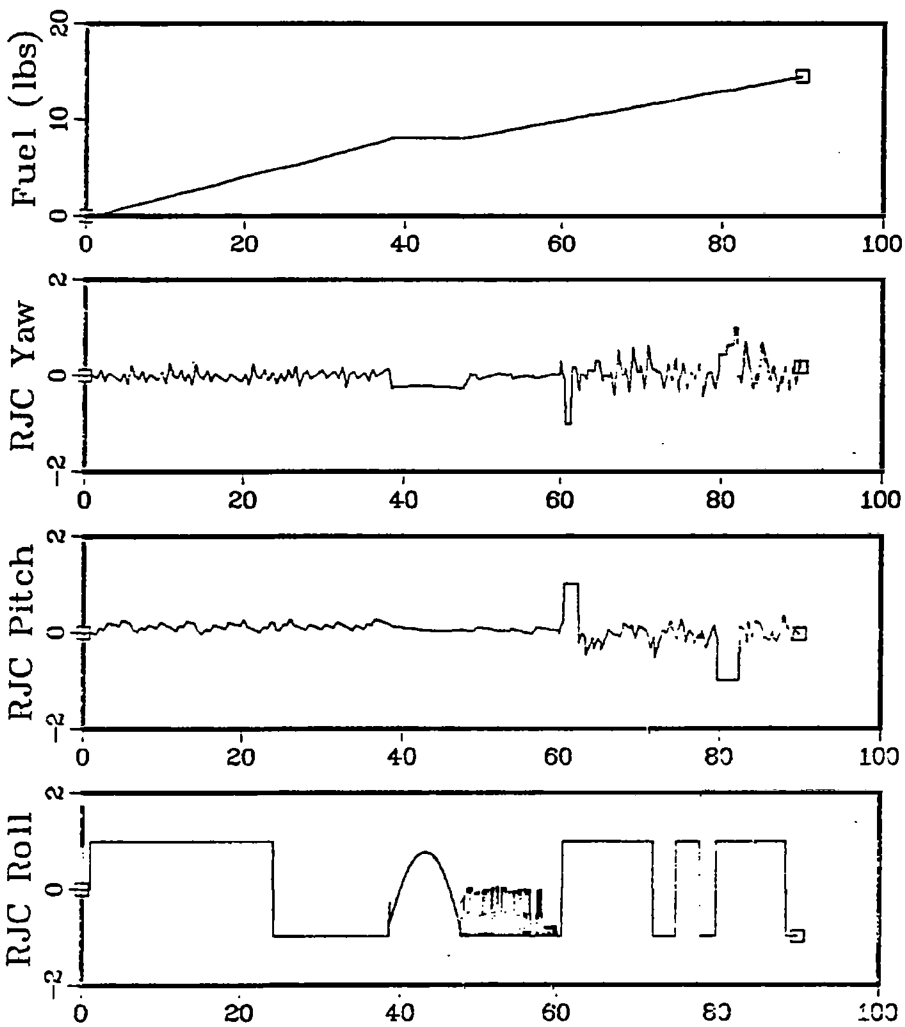
ω_z
-0.02
0.00
0.02
0.04
0
20
40
60
80
100
ω_y
-0.05
0.00
0.05
ω_x
-0.2
0.0
0.2
0.4
ψ
-0.2
-0.1
0.0
0.1
θ
ϕ
5

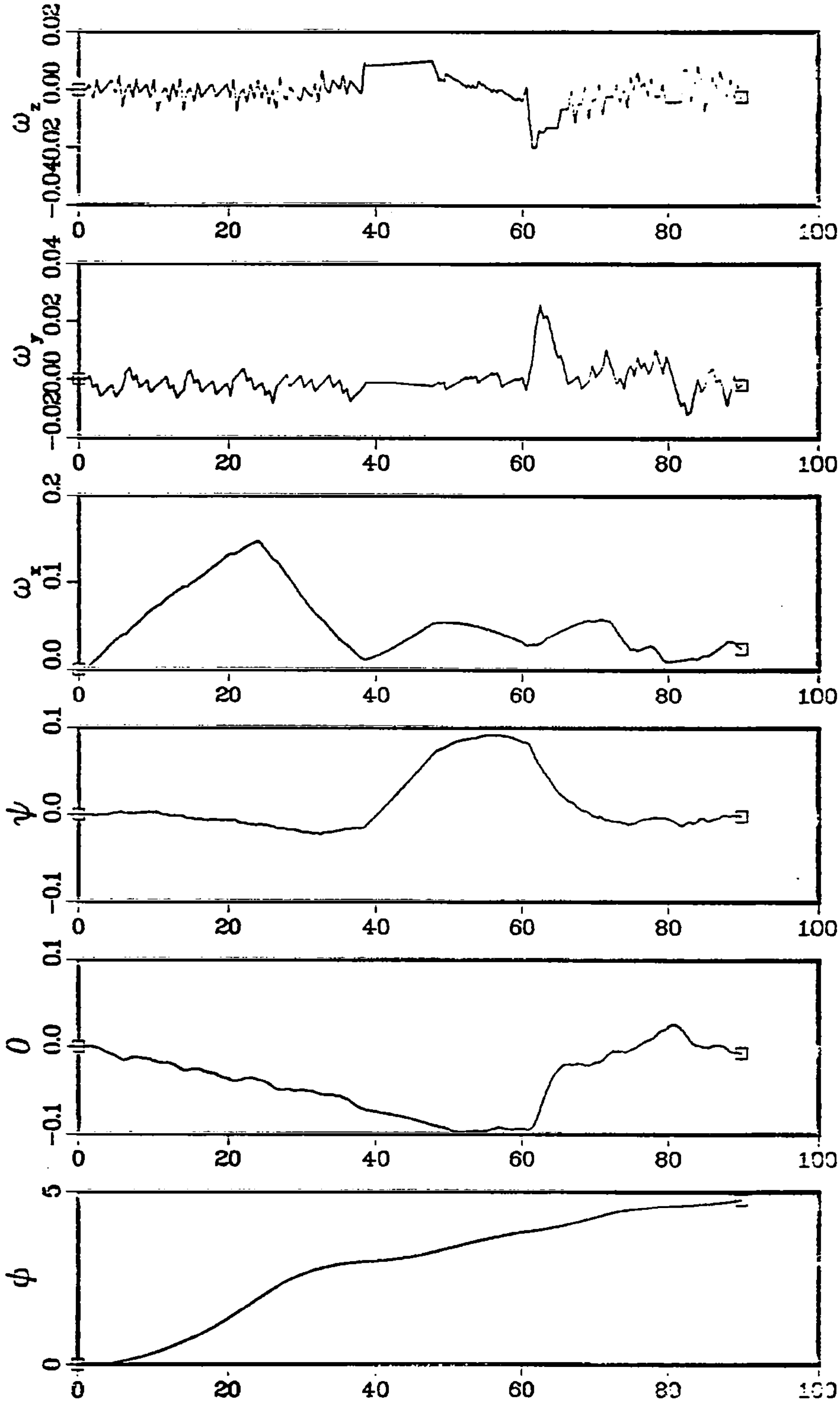
5° Roll Maneuver

rl = .02 °/sec , db = .5°

at 60 sec set

rl = .01 °/sec , db = .1°





ω_z
0.02
0.00
−0.02
−0.04
ω_y
0.04
0.02
0.00
−0.02
ω_x
0.2
0.1
0.0
ψ
0.1
0.0
−0.1
θ
0.1
0.0
−0.1
φ
5
0
0
20
40
60
80
100