LSS/PROPULSION INTERACTIONS STUDIES

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LSS/PROPULSION INTERACTIONS STUDIES

- PROPULSION REQUIREMENTS
- PROPULSION TECHNOLOGIES
- INTERACTION ISSUES/PROBLEMS
- LSS/STATIC LOAD INTERACTION ANALYSIS
- CONCLUSIONS

Propulsion requirements for LSS missions are similar to requirements for current missions, except that demands on both primary and auxiliary propulsion may be greater for LSS missions than they are for current missions, for reasons that will be discussed later. The only propulsion requirement peculiar to LSS spacecraft is figure control, as current spacecraft are rigid or virtually so.

PROPULSION REQUIREMENTS FOR LSS MISSIONS

▲ PRIMARY PROPULSION
- LAUNCH TO LOW EARTH ORBIT
- ORBIT TRANSFER

▲ AUXILIARY PROPULSION
- ORBIT TRANSFER
- STATION KEEPING
- FIGURE CONTROL
- POINTING

The applicable propulsion technologies for LSS are listed on this figure.

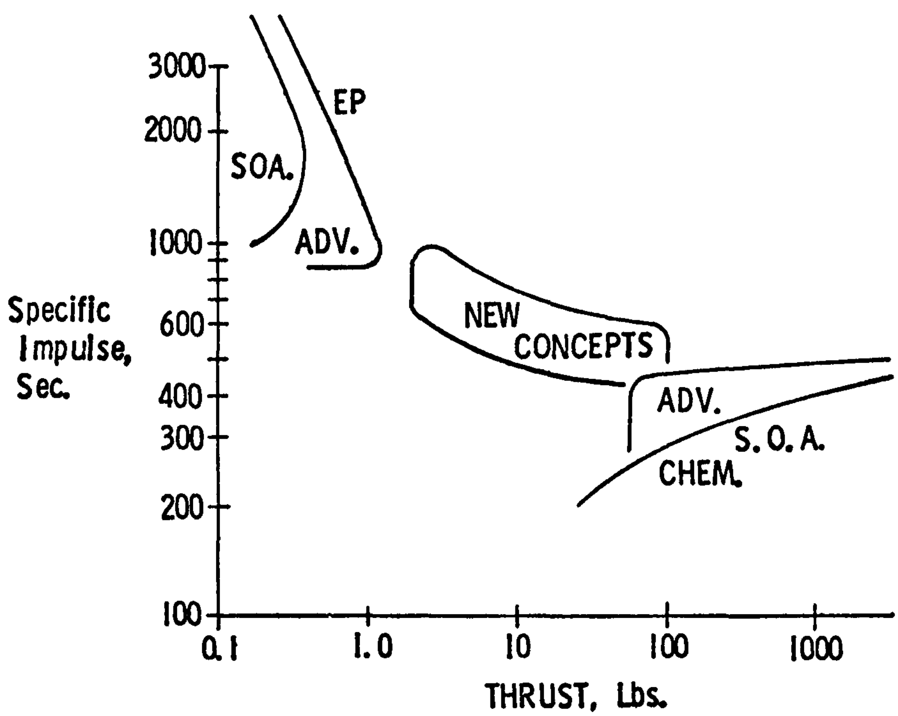
APPLICABLE PROPULSION TECHNOLOGIES

- ELECTRIC
- CHEMICAL
  - HIGH THRUST
  - LOW THRUST
- ADVANCED CONCEPTS

This figure describes the current status of low-thrust technology and the direction in which technology development is heading. Electric propulsion is characterized by low-thrust levels but high specific impulses. Improvements in the state of the art are directed toward increasing the thrust level without great sacrifice of specific impulse. Chemical propulsion, on the other hand, is characterized by relatively high thrust but low specific impulse. Technology efforts in chemical propulsion are aimed at improving the specific impulse and extending the lifetime of low-thrust propulsion systems.

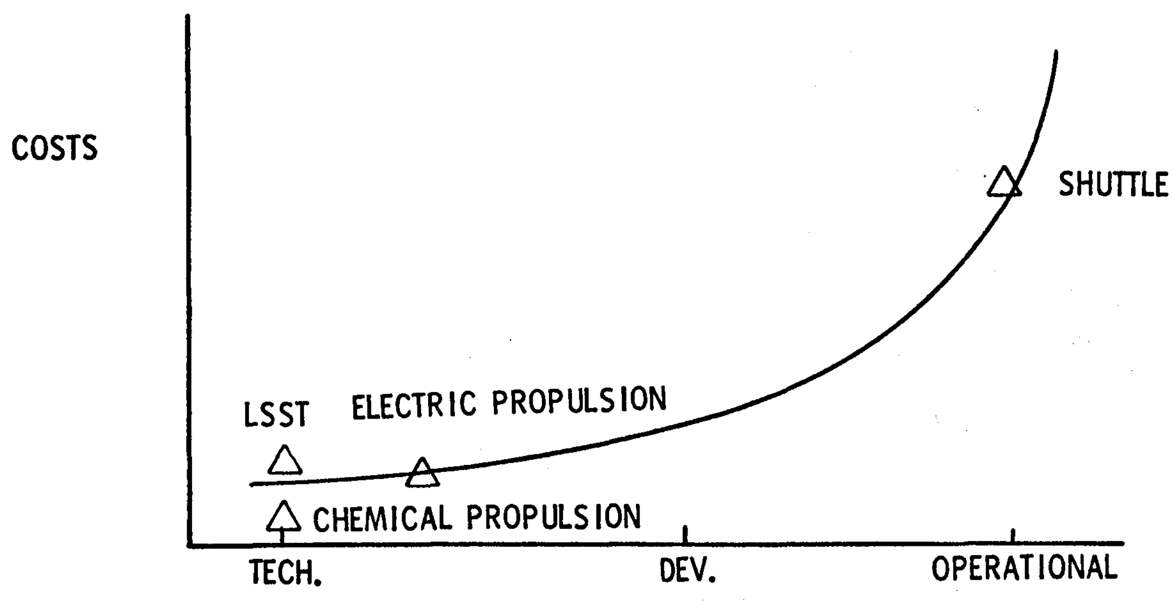
New concepts in propulsion tend to lie in the region between electric and chemical propulsion both in terms of thrust level and specific impulse.

PROPULSION TECHNOLOGY STATUS



With the exception of the Apollo program, virtually all spacecraft to this point were designed to satisfy the launch environment associated with an existing launch vehicle (usually a derivative of military development). With very minor exceptions, all compromises were of necessity on the spacecraft side of the interface. With LSS and low-thrust propulsion, we are in a new situation which offers many opportunities to optimize the propulsion/LSS system to maximize capability at minimum cost. The "cartoon" illustrates the opportunity we have. LSST and chemical propulsion are at the technology level. Electric propulsion, at least in certain respects, is moving toward the development level. Of the required components, only the Shuttle has reached the operational level where changes to specifically accommodate LSS would be prohibitively expensive. If we direct our technology efforts wisely, we can anticipate problems and grasp opportunities to maximize capability and minimize costs. Our failures will become progressively more expensive to correct as we move toward the operational stage.

COST IMPACT OF PROGRAM DECISIONS



-FAILURE TO ANTICIPATE PROBLEMS/OPPORTUNITIES MORE COSTLY AS PROJECTS MATURE

The next several charts are an attempt by LeRC to scope the LSS/propulsion interface problem from the propulsion point-of-view. Specific results have been avoided to highlight the many interactions that exist. The various areas of interaction between the propulsion system and LSS are outlined. The triangles indicate areas of interaction that are or have been investigated by LeRC or its contractors.

INTERACTION ISSUES / PROBLEMS

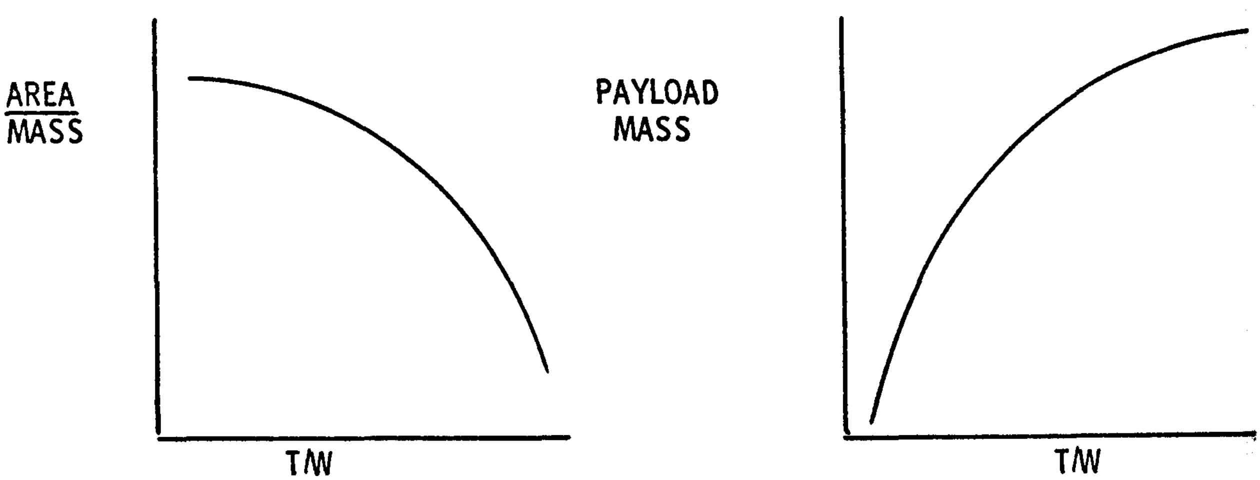
- STRUCTURAL EFFECTS
  - △ STATIC LOADS
  - △ DYNAMIC LOADS
  - \- LAUNCH LOADS
  - △ CONTROL INTERACTIONS
  - △ THRUST DISTRIBUTION
  - △ THROTTLING ($\approx$ CONSTANT T/W)

△ INDICATES ON-GOING OR COMPLETED LeRC ACTIVITY

This figure illustrates the static load/LSS interaction problem. On the left, the effect of T/W on AREA/MASS is shown, indicating that as T/W increases, the structure must be "beefed-up" to withstand the loads. On the right, the payload response to T/W is shown, indicating that over the range of interest, payload increases with T/W. By combining these data, the effect of T/W or thrust on LSS area may be derived. The results of such combinations are shown in some of the following presentations. Such data are very interesting, but recognition of the specific assumptions embedded in such data is at least as important as the data themselves. Careful consideration of a wide collection of both LSS and propulsion data will be necessary to fully appreciate our situation with regard to the static load/LSS interaction.

There are data available for this particular interaction. For other interactions we may know the abscissa and ordinates, but have little or no data. Still less defined, we may be able to intuitively recognize an interaction, but have difficulty specifying the variables. Of most concern are those interactions of these complex systems which we fail to recognize and neglect to plan for.

CHARACTERISTICS OF STATIC LOAD /LSS INTERACTION
PRIMARY PROPULSION, ORBIT RAISING



- AREA INCREASES BUT PAYLOAD DECREASES AS T/W DECREASES

This chart lists some environmental interactions. Most of these interactions are independent of the propulsion choice - electric or chemical.

ISSUES / PROBLEMS (Cont'd)

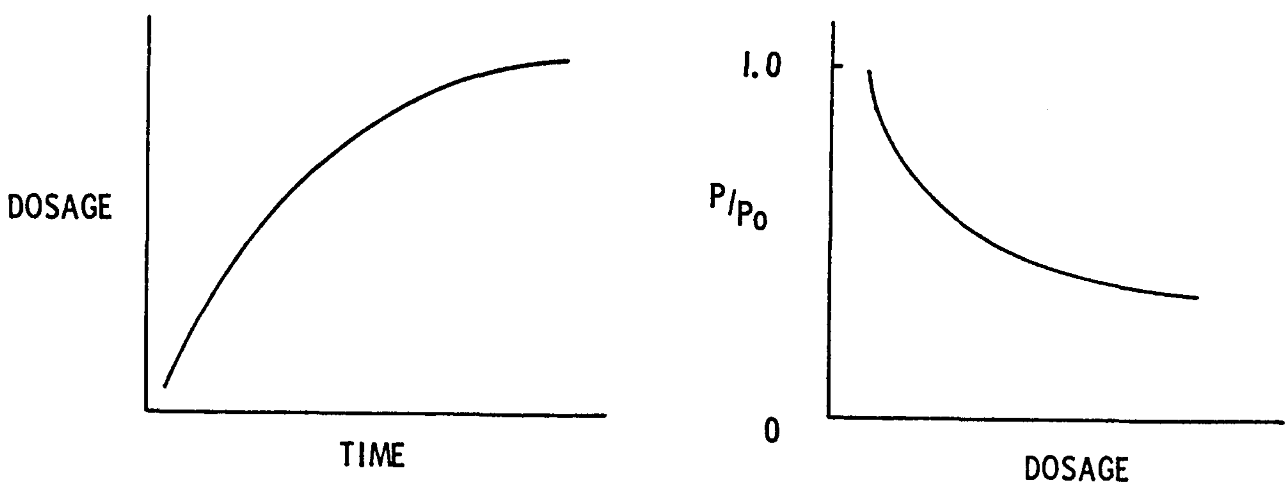
- ENVIRONMENTAL INTERACTIONS

△	RADIATION EFFECTS
△	LIFE & DEGRADATION
-	HEATING (PROPULSION & PAYLOAD)
-	ORIENTATION
△	DRAG
△	SPACECRAFT CHARGING
△	PROPULSION EFFLUENTS

This chart illustrates one of the environmental concerns associated primarily with solar electric propulsion. As is well known, passage through the Van Allen radiation belts damages solar cells, reducing the power available for propulsion. The loss of power is a function of dosage and the susceptibility to damage of the cells. The mission design (which is spacecraft and mission dependent) affects the radiation dosage and the protection afforded the cells (by glass covers, for instance) affects the weight of the propulsion system, which in turn affects the spacecraft. If the spacecraft is supplying the power for the propulsion system, any reduction in power reduces power available for propulsion. For solar electric propulsion systems, these interactions should be considered to optimize the system.

RADIATION EFFECTS

SOLAR CELLS



- RADIATION ENVIRONMENT WILL AFFECT POWER AVAILABLE FOR PROPULSION

Control interactions between the LSS and the propulsion system promise to be some of the more difficult interactions to investigate, not only because of the modeling problems for such complex spacecraft, but also because ground testing of control systems may prove impossible. That is to say, considerable investment in space-based experimentation may be required before models can be shown to accurately represent structural characteristics.

Up to the present, no provision has been made to deorbit unclassified spacecraft when their useful lifetimes are completed. To deorbit such spacecraft, a propulsion system in working order must be available, either by a system on the spacecraft at the end of its mission or by attaching a system which has been sent to perform that task. In either case, the requirement (if real) will affect the propulsion system, propellants, structure, and/or control systems.

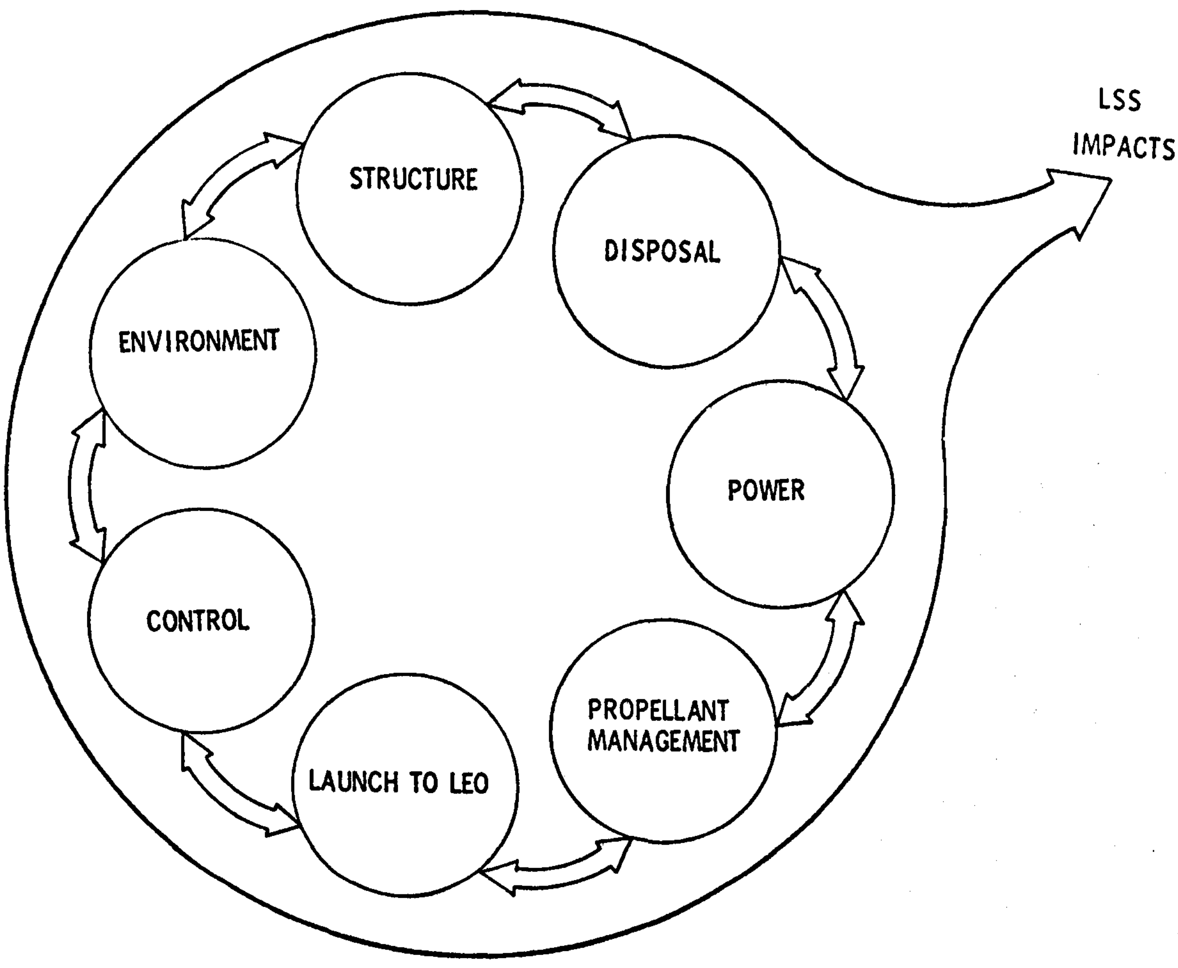
The Shuttle launch environment will also affect the spacecraft propulsion system in many ways, particularly when crew safety considerations are included in the system choice.

ISSUES / PROBLEMS (Cont'd)

- CONTROL INTERACTIONS
  - △ LARGE FLEXIBLE STRUCTURE
  - △ LIFETIME
  - △ NON-NEGLIGIBLE FORCES (GRAVITY GRADIENT & SOLAR PRESSURE)
  - \- RENDEZVOUS AND DOCKING REQUIREMENTS
- DISPOSAL OF DEBRIS / OBSOLETE SPACECRAFT
  - △ PROPULSION LIFETIME
  - \- RENDEZVOUS AND DOCKING REQUIREMENTS
- LAUNCH TO LOW EARTH ORBIT CONSTRAINTS
  - △ DENSITY
  - \- CENTER OF GRAVITY
  - \- CRADLE/BRACE PENALTIES
  - △ VOLUME LIMITATIONS

After consideration of all these interactions it becomes apparent that LSS/propulsion interactions are large, significant, interrelated, and complex. Each of the interactions affects the others in ways and to an extent not previously encountered. The results of the sum total of the interactions will greatly affect LSS spacecraft design and capability.

LSS/PROPULSION INTERACTIONS



To complete our list of interactions, propellant management will affect and be affected by the interactions listed up to this point in evident ways. In turn, propellant management limitations will affect those other interactions. A similar situation exists with power interactions.

It appears clear to us that to a greater extent than was necessary (or possible) earlier, analysis of the TOTAL interaction between the spacecraft and propulsion system will be essential to providing maximum capability at minimum cost for LSS spacecraft.

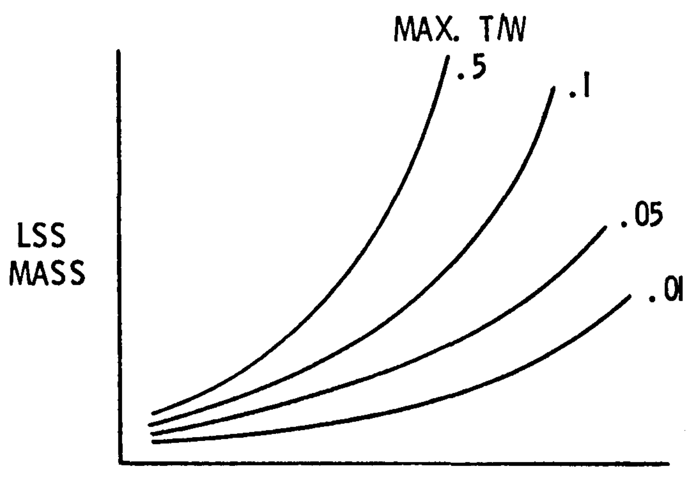
ISSUES/PROBLEMS (Cont'd)

- PROPELLANT MANAGEMENT
  - △ PROPULSION CONFIGURATION
  - △ PROPELLANT CHOICE
  - △ RESTART REQUIREMENTS
- POWER INTERACTIONS
  - SPACECRAFT POWER REQUIREMENTS & AVAILABILITY
  - PROPULSION POWER REQUIREMENTS & AVAILABILITY

To return to a discussion of the investigation of the static load/LSS interaction. The next four viewgraphs are a description of on-going in-house analytical activities in this area. The information on figure 14 is characteristic of the type of data needed to describe the sensitivity of LSS mass to T/W ratio. There are limited data of this sort available and they will vary significantly for different LSS concepts. Before an adequate determination can be made of the proper thrust level for a low-thrust chemical propulsion system, data of this type representative of the spectrum of large space structures will be needed.

PRELIMINARY INVESTIGATION OF STATIC LOAD / LSS INTERACTION

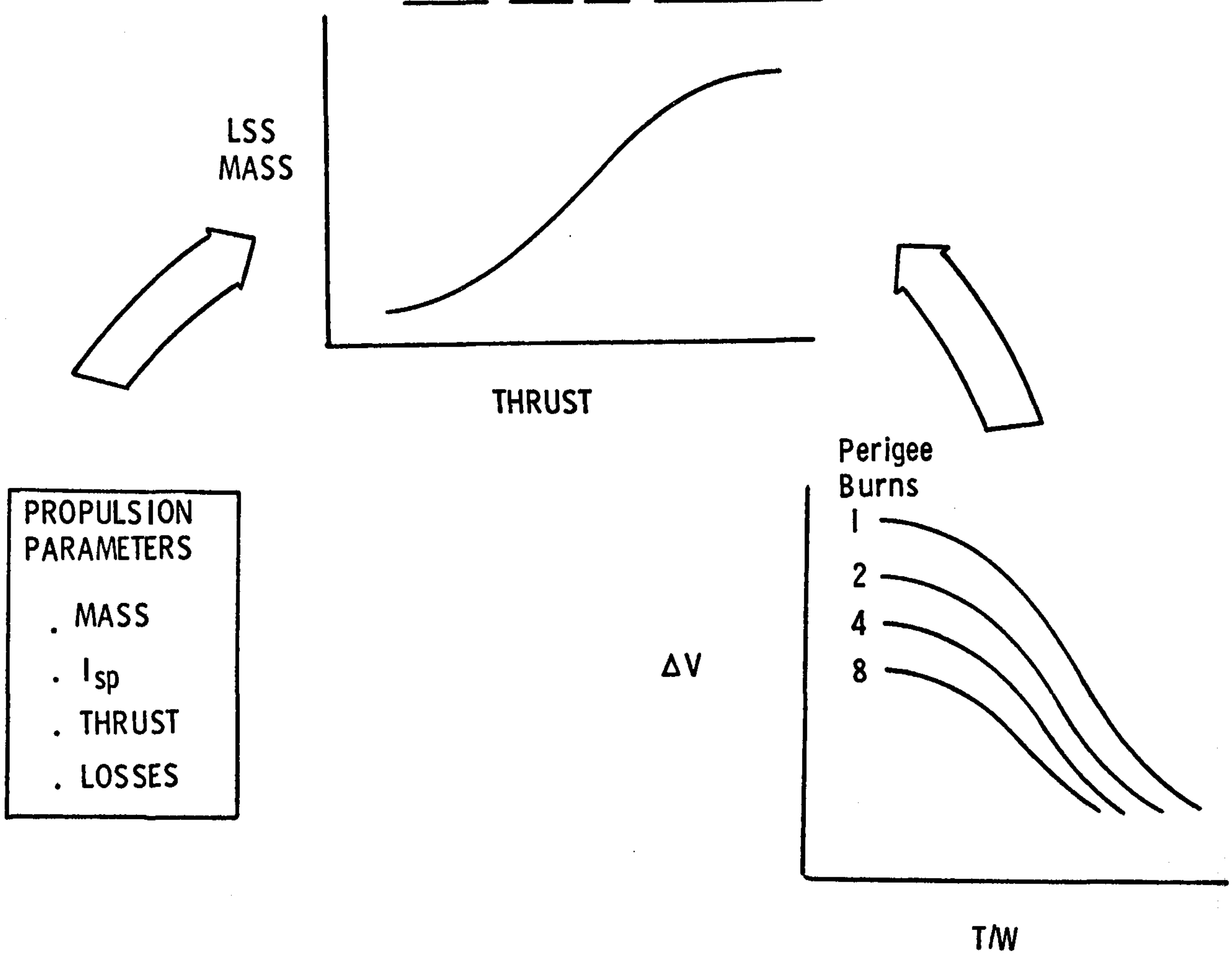
PRIMARY PROPULSION, ORBIT TRANSFER



- LIMITED DATA AVAILABLE
- WILL VARY SIGNIFICANTLY FOR DIFFERENT CONCEPTS

On the propulsion side, performance data as a function of T/W ratio are required. These data are dependent on propulsion parameters (as shown) and on trajectory assumptions (ΔV). The ΔV data available for the thrust-to-weight levels characteristic of low-thrust propulsion systems are not minimum. The trajectories are not optimum. LeRC is sponsoring a grant with Dr. John Breakwell of Stanford to investigate this problem.

PRELIMINARY INVESTIGATION OF STATIC LOAD/LSS INTERACTION



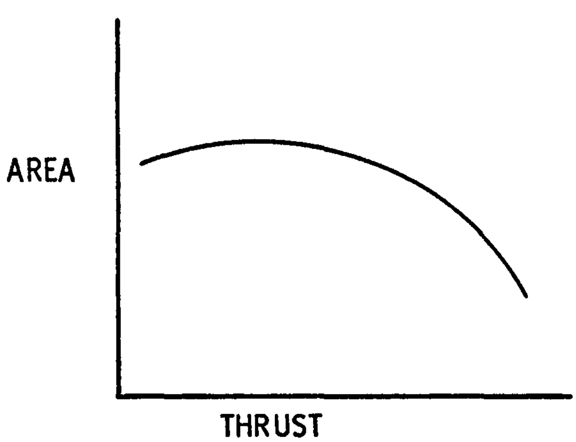
By combining information from figures 14 and 15, LSS area as a function of thrust level may be obtained. We are interested in obtaining a spectrum of such data in order to span the region of interest and understand the relationship between propulsion system thrust level and LSS area.

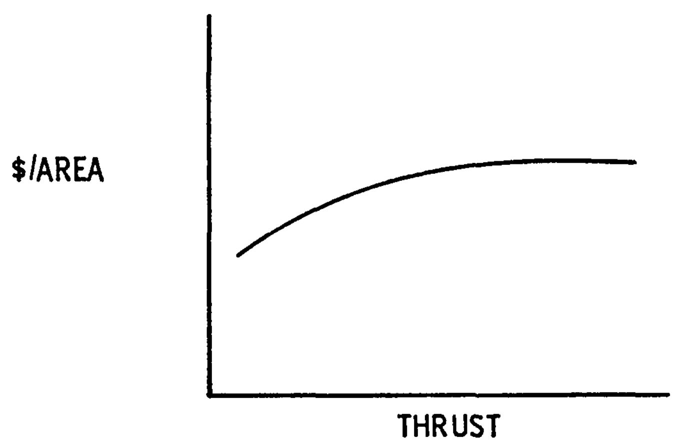
Also of interest is the cost per unit area as a function of thrust. Data of this sort are necessarily less precise than area/performance calculations, but may be helpful in understanding if influential factors involved in costs are understood.

PRELIMINARY INVESTIGATION OF STATIC LOAD/LSS INTERACTION

PRIMARY PROPULSION, ORBIT TRANSFER

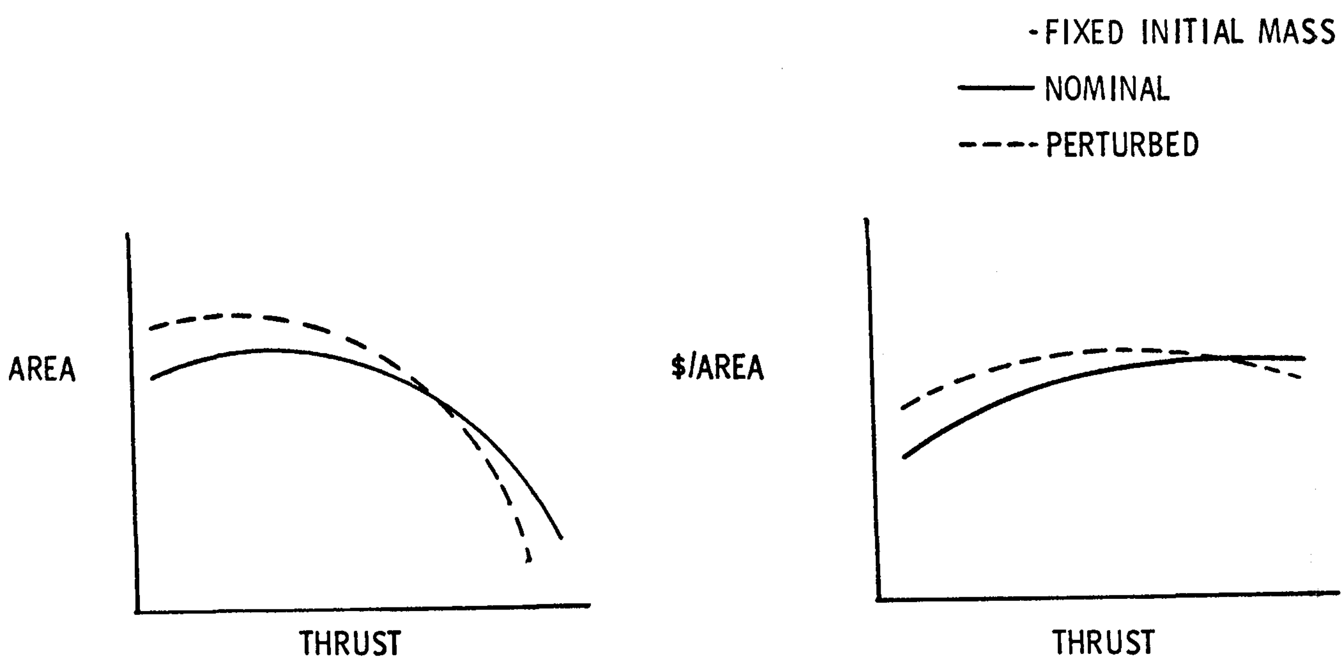
- FIXED INITIAL MASS





In planning technology direction it will be helpful to perform perturbation or sensitivity studies in order to understand the impact of altering propulsion or trajectory parameters and to evaluate the influence of such parameters on capability or cost.

PRELIMINARY INVESTIGATION OF STATIC LOAD/LSS INTERACTION
PRIMARY PROPULSION, ORBIT TRANSFER
PERTURBATION STUDIES



- PERTURBATION STUDIES MAY BE USEFUL TO EXAMINE TECHNOLOGY OPTIONS

We have identified many interactions between the propulsion system and the LSS payload. Further, we have observed that the interactions are not independent and must be evaluated together to accurately assess the total interaction of the propulsion system and the LSS payload. LeRC is investigating some of these interactions either in-house or by contracted effort.

LeRC is also convinced that because of the intensity of the interactions between the propulsion system and the LSS payload, careful collaboration between the payload and propulsion technology efforts will be required to avoid misdirection and exploit unique opportunities.

CONCLUSIONS

- MANY INTERACTIONS IN LSS/PROPULSION INTERFACE
- LeRC INVESTIGATING SOME OF THEM
- STATIC LOAD/LSS INTERACTION DISCUSSED IN SOME DETAIL
- CHANCE TO AVOID MISTAKES AND TAKE ADVANTAGE OF OPPORTUNITIES.