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# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY(OEPSS)

## OEPSS Video Script

30 September 1992


Prepared by
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Edited by
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## OEPSS Video Abstract

The OEPSS video film, along with the OEPSS Databooks, provides a data base of current launch experience that will be useful for design of future expendable and reusable launch systems. The focus is on the launch processing of propulsion systems. A brief 15-minute overview of the OEPSS study results is found at the beginning of the film. The remainder of the film discusses in more detail: current ground operations at the Kennedy Space Center; typical operations issues and problems; critical operations technologies; and propulsion architecture concepts that will substantially increase the operational efficiency of booster and space propulsion systems. The impact of system architecture on the launch site and its facility infrastructure is emphasized. Finally, a particularly valuable analytical tool, developed during the OEPSS study, that will provide for the "first time" a quantitative measure of operations efficiency for a propulsion system is described.

## OEPSS Video

| Segment | Title | Time | Total Time |
|---|---|---|---|
| 1 | Introduction | 3:49 | 3:49 |
| 2 | Overview | 10:13 | 14:02 |
| 3 | Launch Experience | 3:27 | 17:29 |
| 4 | Operations Problems | 10:37 | 28:06 |
| 5 | Operations Technology | 5:36 | 33:42 |
| 6 | Design Concepts | 14:04 | 47:46 |
| 7 | Launch Site | 4:12 | 51:58 |
| 8 | Launch Operations Index | 5:33 | 56:91 |
| 9 | Space Operations | 3:48 | 60:39 |
| 10 | Workshops | 1:44 | 62:23 |
| 11 | Databook | 4:14 | 66:37 |
| 12 | Summary (wrap-up) | 2:10 | 68:47 |

14:02

54:45

## INTRODUCTION--SEGMENT 1

1 FADE IN:

2 VIDEO 0-1 THROUGH 0-6

3 GRAPHIC 1-1

4 GRAPHIC 1-2

DISSOLVE TO:

5 VIDEO 1-2A MONTAGE OF ROCKET LAUNCHES

The United States space program has been extremely successful in delivering payloads to space using expendable and reusable launch vehicles. These vehicles include the Saturn Five, Atlas/Centaur, Delta, Titan and the Space Shuttle. Current launch systems, by virtue of their sophisticated design, have resulted in complex ground support and facility requirements. These conditions have resulted in tedius and time-consuming prelaunch processing that ultimately produces operational problems, launch delays and, therefore, high operations cost.

6 GRAPHIC 1-3

Current experience shows that operations costs for expendable and reusable launch vehicles can be as high as thirty to forty-five percent of the total recurring cost per flight.

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| 7 GRAPHIC 1-4 | Experience to date also shows there have been more flights delayed than launched on time. The average on-time dependability in ground processing for all expendable and reusable launch vehicles is only twenty-four percent, compared to over ninety-five percent for delivering payload into orbit after lift-off. |
| 8 VIDEO 1-5A | If the United States is to remain in the internationally competitive environment, future launch systems must deliver payloads at a lower cost. |
| 9 GRAPHIC 1-6 | To achieve this goal, future launch vehicle designs must be made simpler to process. This translates into more operationally efficient systems at the launch site. |
| 10 GRAPHIC 1-5 | Future costs to deliver payloads into orbit must be at least ten times lower than current cost. Based on a recent study conducted by the Boeing Aerospace Operations entitled, Shuttle Ground Operations Efficiencies and Technologies--also known by it's acronym |

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| 11 GRAPHIC 1-6A | SGOET, the ground processing for propulsion systems was identified as an area that needs to be made more operationally efficient. As a result, NASA Kennedy Space Center through the Advanced Launch System, and the NASA Air Force Joint Program Office, contracted the Rocketdyne Division of Rockwell International to conduct the operationally efficient system study referred to by the acronym OEPSS. This study was made to identify major operations problems and cost-drivers stemming from propulsion designs. |
| 12 GRAPHIC 1-7 | Thus, a propulsion-oriented team made up of Rocketdyne, the Space Systems Division of Rockwell International, and Boeing Aerospace Operations, was formed to conduct the OEPSS study. This very comprehensive operations study is the subject of this video. |
| 13 GRAPHIC 1-7 | |
| 14 GRAPHIC 1-8A | This video will highlight the following areas of study: |

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| 15 | GRAPHIC 1-8B | Launch experience, |
| 16 | GRAPHIC 1-8C | operations problems, |
| 17 | GRAPHIC 1-8D | operations technologies, |
| 18 | GRAPHIC 1-8E | operationally efficient design concepts, |
| 19 | GRAPHIC 1-8F | operationally efficient launch site, |
| 20 | GRAPHIC 1-8G | launch operations index, |
| 21 | GRAPHIC 1-8H | space operations, |
| 22 | GRAPHIC 1-8I | workshops, and databooks. Before presenting the overall results of this study, a brief overview will be presented. |
| | | DISSOLVE TO: |
| 23 | TRANSITION GRAPHIC TO: OEPSS OVERVIEW GRAPHIC 2-1 | |

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| 1 | GRAPHIC 2-1: OEPSS OVERVIEW | |
| | | DISSOLVE TO: |
| 2 | GRAPHIC 2-2A | The traditional design and development cycle for propulsion systems in the past has been a serial process of |
| 3 | GRAPHIC 2-2B | design, |
| 4 | GRAPHIC 2-2C | build, |
| 5 | GRAPHIC 2-2D | and operate. The operator-user finds himself at the end of the line supporting the propulsion design the best he can. Because adequate operational requirements have not been carefully considered early in the design cycle, extremely complex launch processing and extensive ground support requirements have resulted. |
| 6 | GRAPHIC 2-3 | In the design of future propulsion systems, it is now clear that operational requirements must drive the design cycle and become interactive throughout the design cycle. This prevents operational support from being an afterthought. |

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| 7 | GRAPHIC 2-4 | Operational efficiency is like "quality." It cannot be achieved simply by inspection. It must be designed into the product from the very beginning. |
| 8 | GRAPHIC 2-5A | The large launch site experience we have today can now be used to support future propulsion designs. |
| 9 | GRAPHIC 2-5B | It is better and less costly to avoid a problem in the design phase than to try to solve the problem during the operations phase. |
| 10 | GRAPHIC 2-6 | In the past, propulsion systems typically consist of packaging multiple systems independently designed, developed and supported in the field. This has created the problem of requiring a complex network of ground support systems to perform inspection, maintenance and checkout on large numbers of components and system interfaces. |

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| 11 GRAPHIC 2-7A | One objective of the OEPSS study is to |
| 12 GRAPHIC 2-7B | identify major operations problems encountered during launch processing of propulsion systems. Another objective is to |
| 13 GRAPHIC 2-7C | identify technology that will eliminate these problems or eliminate unnecessary systems. |
| 14 GRAPHIC 2-7D | A third objective is to recommend approaches for future design, from an operator's view, that will simplify the propulsion system. A design approach which the OEPSS study feels has significant operational simplicity and merit is one that addresses propulsion as a highly integrated total system from tankage, fluid system, structure, thrust chamber, and turbopumps down to the control system. |
| 15 GRAPHIC 2-7E | This overview will describe the scope and some brief results of the OEPSS study. |

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| 1 GRAPHIC 12-1 | Launch experience has shown us that operations problems, launch delays and high operations cost are a direct result of |
| 2 GRAPHIC 2-8 | complex designs. Too many parts and interfaces that are not readily accessible and serviceable results in extensive manpower, equipment, and time required for launch processing. Too many separate independent systems simply exacerbates this problem. The solution? Achieve a simple design from the beginning. The key to a simple design is operability. This leads to operational efficiency. |
| 3 GRAPHIC 12-1 LAUNCH EXPERIENCE | Launch experience has also shown that highly specialized ground support equipment, many facilities, and the large operations support infrastructure are a direct result of launch processing of complex designs. |

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| 4 | GRAPHIC 11-7 | Operations problems have been encountered throughout the launch cycle from assembly, checkout, launch and recovery. Some of the prominent operations problems like closed-aft compartments, fluid system leakage, hydraulic and pneumatic systems, and multiple propellant requirements are highlighted in the video. |
| 5 | GRAPHIC 12-1 OPERATIONS TECHNOLOGIES | Operations technologies that will enable new designs to be simpler and more operationally efficient have been identified by the OEPSS study. |
| 6 | GRAPHIC 11-9 | These technologies not only will reduce many operations problems but also will eliminate special facilities and support infrastructure that contributes to operations cost. The following technologies are highlighted: Electromechanical actuator, No purge pump seal, Oxidizer-rich turbine, No purge combustion chamber, and the combined oxygen/hydrogen system. |

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| 7 GRAPHIC 12-1 DESIGN CONCEPTS | By way of illustration, from the operator-user point of view, the OEPSS study describes a propulsion concept that achieves simple design and operational efficiency. By integrating and consolidating components and functions, and avoiding separate independent, redundant systems, the number of hardware parts were greatly reduced. High operability was achieved. |
| 8 GRAPHIC 6-6 | A fully integrated, LOX/LH2 booster for an Advanced Launch System is highlighted in the video. This design concept is robust and has high reliability and good engine-out capability. Also highlighted in the video is a |
| 9 GRAPHIC 6-30 | LOX-tank aft concept similar to the Jupiter vehicle. This concept simplifies preconditioning and checkout of propellant lines. It also eliminates potential gysering in long LOX lines which is a criticality-one failure. Parallel tanks, similar to Saturn IB, and concentric tanks are also shown as options. |

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| 10 | GRAPHIC 12-1 LAUNCH SITE | The OEPSS study has identified operations technologies for propulsion designs that will avoid operations problems and eliminate complex operations requirements. If these technologies are successfully applied, then the launch site can be greatly simplified and made operationally efficient.<br>Moreover, it will be capable of quick response and have low operations cost. |
| 11 | GRAPHIC 12-1 LOI | The OEPSS study has developed a parameter to measure the operability of a propulsion design. This parameter utilizes launch experience for a baseline and is called the Launch Operations Index or LOI. The calculation of LOI is similar to the QFD, A-1 Matrix that determines how well a product meets what the customer wants. In this case, the product is the propulsion hardware and the customer is the operator-user. The LOI can be used for evaluating concepts, detail designs, or to compare two or more designs. |

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| 12 | GRAPHIC 8-2 | The Launch Operations Index is an important new parameter needed for evaluating propulsion designs, along with the basic parameters for cost, performance and reliability. |
| 13 | GRAPHIC 12-1 SPACE OPERATIONS | A propulsion system in space must operate reliably and safely on demand. Space is a hostile environment. The system must be made maintenance-free and operations-free.<br>Again, the key to operability is make the design simple. Two examples of operationally efficient systems described in this video are the integrated modular |
| 14 | GRAPHIC 9-10 | Lunar Lander engine and the Advanced Upper Stage engine. The integrated modular engine shown for the advanced upper stage vehicle is similar to the integrated concept used for the lox/hydrogen booster for the advanced launch system. |

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| 15 | GRAPHIC 12-1 WORKSHOPS | One of the major objectives of the OEPSS study was to provide feedback of launch experience and data back to design centers. The OEPSS Team accomplished this by conducting on-site workshops with vehicle and propulsion design contractors. Workshops with other technical groups also were held. |
| 16 | GRAPHIC 12-1 DATABOOKS | Databooks summarizing he results of the OEPSS study have been prepared and issued. This video is only a synopsis of the total material contained in these Databooks. The Databooks and video are means for communicating launch experience back to the designers. |
| 17 | GRAPHIC 12-1 LAUNCH SYSTEMS | Finally, to achieve operability, or operational efficiency, launch experience must be an interactive part of the propulsion design cycle. Operational efficiency is the key to the design of a launch system that is simple, reliable, low cost, responsive and dependable. |

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| 18 | GRAPHIC 12-2 | The bottom-line is not to achieve operational efficiency simply to reduce operations cost, but to reduce the time and cost all the way up the line through the whole design cycle. From the designers to the builders--from testing to qualifying--from the installation to the servicing, and finally to the launch and flight: All of these areas will reduce time and costs. |
| 19 | GRAPHIC 12-2 | If a part or a system can be simplified or eliminated, the payback in total cost savings can be exponential.<br>The remainder of the video will review the items covered by this overview in considerably more detail. |

**SEGMENT 3**

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| 1 | GRAPHIC 3-1<br>LAUNCH EXPERIENCE | |
| | | DISSOLVE TO: |
| 2 | GRAPHIC 3-2A | Our past launch experience has shown us why we have operations problems, launch delays, and high operations cost. |
| 3 | GRAPHIC 3-2B | First, the design of launch vehicles is very complex, with reusability further exacerbating the problem. |
| 4 | GRAPHIC 3-2C | There are also too many parts and system interfaces, many of which are |
| 5 | GRAPHIC 3-2D | not readily accessible and serviceable. All this results in |
| 6 | GRAPHIC 3-2E | extensive manpower, equipment, and time required for launch processing. Also, there are |
| 7 | GRAPHIC 3-2F | too many different propellants and fluid systems in each vehicle. These differences require sometimes rather unique |
| 8 | GRAPHIC 3-2G | specialized ground support equipment and facilities. |
| 9 | GRAPHIC 3-3A | It's quite clear that complex operational requirements are a direct result of a complex design. |

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| 10 | GRAPHIC 3-3B | And a complex design causes severe compromises to system operability and supportability. It's also quite clear that design |
| 11 | GRAPHIC 3-3C | complexity starts from the beginning of the design. |
| 12 | GRAPHIC 3-3D | If the operational requirements were not design factors early in design, then operability will be a problem at the end of design. |
| 13 | GRAPHIC 3-4A | The key lesson to be learned from launch experience is to |
| 14 | GRAPHIC 3-4B | make the design simple and operable. |
| 15 | GRAPHIC 3-4C | Reductions must occur in the number of independent components and artificial system interfaces. |
| 16 | GRAPHIC 3-4D | The number of fluid systems required by the vehicle must also be reduced to eliminate specialized ground service equipment and facilities. |
| 17 | GRAPHIC 3-4E | The design must integrate major components and systems to eliminate unneeded duplicate parts and functions. |

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| 18 | GRAPHIC 3-5 | In other words, design-out operations problems at the beginning of the design. |
| 19 | GRAPHIC 3-6A | Simple design is synonymous with operability. |
| 20 | GRAPHIC 3-6B | A highly serviceable and |
| 21 | GRAPHIC 3-6C | supportable system is easier to test and check out for flight with |
| 22 | GRAPHIC 3-6D | fewer people and |
| 23 | GRAPHIC 3-6E | shorter time. High operability will help eliminate launch delays and high cost. |
| 24 | GRAPHIC 3-7A | Operability is also the "key" to achieving low cost, |
| 25 | GRAPHIC 3-7B | affordable launch systems that will meet our future goals for |
| 26 | GRAPHIC 3-7C | quick launch response, |
| 27 | GRAPHIC 3-7D | and routine access to space. |
| | | DISSOLVE TO: |
| 28 | GRAPHIC 4-1 | |

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| 1 | GRAPHIC 4-1<br>OPERATIONS PROBLEMS | |
| | | DISSOLVE TO: |
| 2 | GRAPHIC 4-2A | The basic system processing schedule at the |
| 3 | GRAPHIC 4-2B | launch site can be depicted in five phases. First, the flight system hardware is |
| 4 | GRAPHIC 4-2C | received at the launch site. Then, the systems are |
| 5 | GRAPHIC 4-D | processed and verified for operational readiness. This is followed by |
| 6 | GRAPHIC 4-E | integrating the sub-systems into a total system and then an end-to-end |
| 7 | GRAPHIC 4-F | checkout of the total system leading to launch preparation is conducted. If the checkout is successful, a count-down to |
| 8 | GRAPHIC 4-G | launch begins. In the case of |
| 9 | GRAPHIC 4-H | recoverable systems, the launch site plays a major role in |
| 10 | GRAPHIC 4- | retrieving the hardware and turning around selected systems for reuse. |

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| 11 | VIDEO OF LAUNCH COUNTDOWN PROCESS | Launch operations to some are just those activities that occur when the countdown clock begins to tick, and ends when we hear the words, "...and we have liftoff." |
| 12 | VIDEO OF LAUNCH OPERATIONS | However, in reality, it is much, much more complex. Launch operations usually involves many weeks, or in some cases even months, of very intense and time-consuming ground processing activities leading up to the successful launch. |
| 13 | GRAPHIC 4-3 | Flight hardware, in a generic sense, has three major phases in the processing cycle. |
| 14 | GRAPHIC 4-4 AND VIDEO 4-4 | Build it up, |
| 15 | GRAPHIC 4-5 AND VIDEO 4-5 | check it out, |
| 16 | GRAPHIC 4-6 AND VIDEO 4-6 | and launch it. Of course, in the case of recoverable flight hardware, a 4th phase, that of |

17 GRAPHIC 4-6B

recovery and turn-around, would enter the cycle, and could introduce another whole new dimension of processing requirements to the already complex activities.

18 GRAPHIC 4-7

Even a flight subsystem checkout, such as a propulsion system, can be very involved and complex. It requires numerous personnel and their support infrastructure. Interdependency on these various systems makes for a very complex and manpower-intensive operation. Scheduling activities can be a nightmare. It would not be uncommon to encounter this maze of support requirements to get the "OK-to-proceed" just to flip one or two switches, to verify the position, or condition, of a component or subsystem.

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| 19 GRAPHIC 4-8 | Launch site operations complexity really becomes evident when you now consider what's behind the scenes to support the flight subsystem checkout that we just highlighted. In many cases this support operations infrastructure is extensive and could account for at least five times the manpower it takes to check out a complex flight system. |
| 20 AERIAL VIEW OF THE LAUNCH PAD | All too often we tend to focus on the flight vehicle being readied for launch, and as a backdrop, we only see the expanse of the launch pad in total. We do not really see the massive |
| 21 GRAPHIC 4-9 | ground support equipment infrastructure that is required to ultimately accomplish our launch objective. |
| 22 POSSIBLE VIDEO FOOTAGE OF THESE AREAS? | All of the propellant, gas, electrical, and other support commodity systems must be maintained, serviced, and operated. The towers, arms, umbilicals, platforms, require constant attention to insure readiness to support launch operations. |

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| 23 GRAPHIC 4-10 | Ground support equipment that touches flight hardware such as lifting slings, plugs, protective covers, flow measuring devices, hoses, disconnects, filters, cradles--and so forth--require care and attention for each launch processing flow. It is a constant, never-ending cycle. |
| 24 LIVE VIDEO FOOTAGE? | It requires day in and day out, time-consuming activities by multitudes of people to keep everything in a "ready-to-support" condition. How do we reduce this massive support infrastructure? Perhaps a more simple design could be the answer. Our over thirty years of hands-on, |

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| 25 | GRAPHIC 4-11A | operations experience with propulsion systems at the launch site has surfaced numerous concerns. These concerns involve serious processing flow impacts and are major launch operations cost drivers. These concerns are |
| 26 | GRAPHIC 4-11B | serial flow, |
| 27 | GRAPHIC 4-11C | time consuming, |
| 28 | GRAPHIC 4-11D | manpower intensive which results in, |
| 29 | GRAPHIC 4-11E | launch delays and |
| 30 | GRAPHIC 4-11F | high cost. Let's look at several of these operations' issues in more detail. For instance-- |
| 31 | GRAPHIC 4-12A | closed compartments. The impact on ground operations caused by a propulsion system contained within a closed compartment includes tremendous |
| 32 | GRAPHIC 4-12B | safety risks to personnel. Furthermore, the |

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| 33 | GRAPHIC 4-12C | confinement of potential propellant leaks can result in catastrophic failure. These risks introduces the requirement for |
| 34 | GRAPHIC 4-12D | sophisticated ground support equipment to condition and inert the environment for detection of hazardous gases, and for |
| 35 | GRAPHIC 4-12E | sophisticated heat shielding. These requirements severely impairs |
| 36 | GRAPHIC 4-12F | accessibility, and promotes |
| 37 | GRAPHIC 4-12G | serial operations. |
| 38 | GRAPHIC 4-13A | Fluid system leakage, and the necessary corrective actions are major cost drivers at the launch site. The operational impacts include extreme |

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| 39 | GRAPHIC 4-13B | safety hazards especially in a confined space. System integrity verification is |
| 40 | GRAPHIC 4-13C | time consuming, |
| 41 | GRAPHIC 4-13D | manpower intensive, and may require sophisticated ground support equipment including detection equipment. Corrective actions are time consuming and manpower intensive. It requires |
| 42 | GRAPHIC 4-13E | retesting with the possibility of multiple repeats of the operation. Ambient condition leak checks may be successful only to have leaks appear when the system is at its operating environment. |
| 43 | GRAPHIC 4-14A | Hydraulic systems, especially their support infrastructure requirements, add an order of magnitude to the |

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| 44 GRAPHIC 4-14B | complex check-out operations at the launch site. |
| 45 GRAPHIC 4-14C | These complex ground systems include pumping units, gear boxes, prime movers, high pressure piping, filters, gas systems, reservoirs, de-aerators, control systems, thermal conditioning, and so forth -- each and all of which must be serviced and maintained. Also required are |
| 46 GRAPHIC 4-14D | duplicate systems, a ground system to support ground operations, and a flight system to support flight operations. Now, include the mission directed redundancy requirements, and you can well appreciate this type of system being a prime operations cost driver. System integrity verification can require countless hours of circulation, de-aeration/filtering and sampling. Where hydraulic systems exist, you will find that other flight system dependency can drive you to |

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| 47 GRAPHIC 4-14E | serial operations. |
| 48 GRAPHIC 4-15A | Pneumatics system requirements adds another dimension to the launch site operational complexity and costs. |
| 49 GRAPHIC 4-15B | Complex checkout of the pneumatic systems for valve actuators, systems purges and pressurization, and for other gas medium services, requires a complex and costly ground facility infrastructure and an army to maintain it. Vehicle flight systems are complicated, duplicated for redundancy requirements, inter-connected, isolated, filtered, regulated, measured, over-capacity stored, high pressured, orificed for trickling, and distributed. However, the |
| 50 GRAPHIC 4-15C | complex facility on the ground side of this system is orders of magnitude more extensive to receive, store, distribute, pressure-breakdown, regulate, redundant, local and remotely controlled, verified, and maintained leak-free and |

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| 51 GRAPHIC 4-15D | contamination free...and the list goes on. Operations to maintain systems cleanliness, medium purity, and leak-free for a costly commodity, such as helium, are very time consuming and |
| 52 GRAPHIC 4-15E | manpower intensive. |
| 53 GRAPHIC 4-16A | All of our work horse launch vehicles are comprised of more than one propulsive system. In most cases, they operate using multiple different propellant combinations. As an example, you might find one propellant combination for the main engines -- say, LOX/hydrogen, or, LOX/hydrocarbon, only to find that a roll, or reaction, control system is of another propellant. Next, you are most likely to find different propellant combinations as you move up the vehicle to the upper stages. |

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| 54 GRAPHIC 4-16B | Each time we introduce a different commodity to the launch site, especially multiple propellant combinations, we introduce different and greater degrees of complexity to launch operations. Each commodity, or combination thereof, has its own peculiar set of requirements that will impact, or add to operations cost. Each different commodity will require its own dedicated support system. In other words, if you have a vehicle that requires hydrocarbon, cryogenic, and earth storable propellants, each of these will require its own |
| 55 GRAPHIC 4-11C | complex storage facility and distribution system. Each will require a different logistics support base, and each will dictate different complexities in |

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| 56 GRAPHIC 4-12D | handling techniques. This extensive ground and facility support base carries right over to the launch vehicle. Therefore, each propellant combination will have its own pneumatic system, dedicated power and instrumentation, and so forth. Consideration for system simplicity should drive the designer to look at |
| 57 GRAPHIC 4-12E | combining all commodity needs on the vehicle to a single propellant combination. For example, an all LOX/Hydrogen propulsion system might give rise to using this same propulsion grade propellant to power the fuel cells. Furthermore, this same LOX used for propulsion may be used for the environmental control system if it is a manned vehicle. |
| 58 GRAPHIC 4-17A | We have very briefly highlighted five of our major operations concerns at the launch site. In addition to these five, there are at least nineteen other issues that have been identified as major operations problems. These include |

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| 59 | GRAPHIC 4-17B | ocean recovery and refurbishment, |
| 60 | GRAPHIC 4-17C | hypergolic propellants, |
| 61 | GRAPHIC 4-17D | accessibility, |
| 62 | GRAPHIC 4-17E | sophisticated heat shielding, |
| 63 | GRAPHIC 4-17F | excessive components and subsystems, |
| 64 | GRAPHIC 4-17G | lack of hardware integration, |
| 65 | GRAPHIC 4-17H | separate OMS/RCS, |
| 66 | GRAPHIC 4-17I | gimbal system, |
| 67 | GRAPHIC 4-17J | high maintenace hardware, |
| 68 | GRAPHIC 4-17K | ordnance operations, |
| 69 | GRAPHIC 4-17L | retractable umbilical carrier plates, |

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| 70 | GRAPHIC 4-17M | propellant tank pressurization system, |
| 71 | GRAPHIC 4-17N | inert gas purge, |
| 72 | GRAPHIC 4-17O | excessive interfaces, |
| 73 | GRAPHIC 4-17P | conditioning and geysering, |
| 74 | GRAPHIC 4-17Q | preconditioning system, |
| 75 | GRAPHIC 4-17R | expensive commodity usage, |
| 76 | GRAPHIC 4-17S | lack of hardware commonality, |
| 77 | GRAPHIC 4-17T | and system contamination. |

78 REPEAT GRAPHICS 4-17A THROUGH 4-17T

Some of these problems may overlap each other. That's expected since our launch systems are inter-system-dependent. The launch operations problems have been ranked by the OEPSS study in their relative descending order of impact. This is not to mean that system contamination is any less important than closed aft compartments, but from experience, this is a fair order of how these problems impact launch operations.

DISSOLVE TO:

79 GRAPHIC 5-1 OPERATIONS TECHNOLOGY

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| 1 | GRAPHIC 5-1<br>OPERATIONS TECHNOLOGY | |
| | | DISSOLVE TO: |
| 2 | GRAPHIC 5-2A | The OEPSS study has also identified some technologies for eliminating operations problems. These technologies not only will |
| 3 | GRAPHIC 5-2B | reduce the complex ground checkout process, but will |
| 4 | GRAPHIC 5-2C | eliminate some of the massive infrastructure of logistics, supplies, equipment, and facilities associated with these ground checkouts. These technologies will make |
| 5 | GRAPHIC 5-2D | new designs simpler and more operationally efficient. |
| 6 | GRAPHIC 5-3A | The development of an electromechanical system for valve positioning and gimbal actuation will make the propulsion system more operationally efficient. Current launch vehicle propulsion systems have been entirely dependent on hydraulic and pneumatic systems. |

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| 7 | GRAPHIC 5-3B | Eliminating hydraulic and |
| 8 | GRAPHIC 5-3C | pneumatic requirements eliminates a |
| 9 | GRAPHIC 5-3D | fluid commodity, |
| 10 | GRAPHIC 5-3E | simplifies hardware checkout, and eliminates fluid contamination problems. The electro-mechanical system also offers the opportunity to completely |
| 11 | GRAPHIC 5-3F | automate the test and checkout process to verify the integrity of a flight system. |
| 12 | GRAPHIC 5-4A | The development of a no-purge pump seal, |
| 13 | GRAPHIC 5-4B | an oxidizer-rich turbine, and a |
| 14 | GRAPHIC 5-4C | no-purge combustion chamber will make the propulsion system more operationally efficient. |

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| 15 | GRAPHIC 5-5 WITH ANIMATED POINTED ARROWS | Current engine systems are designed to use pneumatics because the oxidizer turbopump requires a helium buffer purge to separate the leakage of fuel-rich turbine gases from the oxidizer being pumped. |
| 16 | GRAPHIC 5-6 | The technology development of a low leakage rate seal which does not require a purge, and where the drain cavity leakage is reduced below flammability limits, will eliminate both pneumatic requirements and helium usage. |
| 17 | GRAPHIC 5-7A | The technology development of an oxidizer-rich turbine will also |
| 18 | GRAPHIC 5-7B | eliminate pneumatic requirements |
| 19 | GRAPHIC 5-7C | and helium usage. This technology will eliminate the need for a buffer purge in the oxidizer turbopump intermediate seal, much like the no-purge pump seal, because the mixing of the oxidizer pump and oxygen-rich turbine leakages would no longer be catastrophic. |

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| 20 | GRAPHIC 5-7C | The technology development includes an oxigen-rich turbine design, an oxygen-rich injector design, and oxygen compatibility of materials. |
| 21 | LIVE VIDEO? | The second largest pneumatic requirement and helium usage in current engines is the purge required prior to engine-start and after engine shut-down. |
| 22 | LIVE VIDEO? | The prestart purges provide an inert environment downstream of the propellant valves to prevent solid air formation on the hydrogen side and avoid hydrogen blowback into the manifolds on the oxygen side. |
| 23 | LIVE VIDEO? | Shutdown purges are used to blow out residual liquid oxygen from the injector manifold to avoid damage to the injector. The technology development of a |
| 24 | GRAPHIC 5-8A | no-purge combustion chamber will eliminate |

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| 25 | GRAPHIC 5-8B | pneumatic requirements and |
| 26 | GRAPHIC 5-8C | helium usage, which will greatly simplify ground operations. This technology development includes the use of the fuel |
| 27 | GRAPHIC 5-8D | tank ullage gases to blow out any air downstream of the main fuel valve just prior to engine start. It also includes the design of low propellant volume |
| 28 | GRAPHIC 5-8E | injector manifolds and close couple oxidizer valves to eliminate the volume of unburned liquid oxygen following shutdown. |
| 29 | GRAPHIC 5-8F | |
| 30 | GRAPHIC 5-9A | A critical area in ground operations discussed earlier is the large number of fluid commodities required to support the launch system. Some launch systems require all of the following commodities; |
| 31 | GRAPHIC 5-9B | propellant grade liquid hydrogen, and liquid oxygen; |

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| 32 | GRAPHIC 5-9C | Hydrazine; |
| 33 | GRAPHIC 5-9D | monomethyl hydrazine; |
| 34 | GRAPHIC 5-9E | nitrogen tetroxide; |
| 35 | GRAPHIC 5-9F | and fuel-cell grade liquid oxygen. The thermal management system also requires |
| 36 | GRAPHIC 5-9G | Freon-21, a liquid florinated hydrocarbon, |
| 37 | GRAPHIC 5-9H | ammonia and water. |
| 38 | VIDEO OR 5-9H | As pointed out earlier, multiple commodities require extensive ground support systems, facilities, and specialized personnel. Handling hypergolic propellants adversely impacts ground operations flow, and fuel-cell grade oxygen is contamination sensitive. The technology development of a |
| 39 | GRAPHIC 5-10A | combined hydrogen/oxygen system that will provide not only |

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| 40 | GRAPHIC 5-10B | main propulsion but also |
| 41 | GRAPHIC 5-10C | orbital maneuvering, reaction control, |
| 42 | GRAPHIC 5-10D | fuel-cells for electric power, and, vehicle |
| 43 | GRAPHIC 5-10E | thermal management, |
| 44 | GRAPHIC 5-10F | and life support will eliminate many |
| 45 | GRAPHIC 5-11A | major operations problems and |
| 46 | GRAPHIC 5-11B | facility requirements. This highly synergistic technology integrates a total propulsion system to the use of a |
| 47 | GRAPHIC 5-11C | single propellant combination operating from a single common tankage and fluid system. |

48 GRAPHIC 5-11 NEW CHART

Recently, Rockwell Space Systems Division completed a design study for NASA Lewis Research Center called the Integrated Oxygen Hydrogen Technology Study or I-HOT. This study investigated the technology required for an integrated, hydrogen-oxygen system that would combine auxiliary propulsion...such as OMS and RCS...with the main propulsion. This video has highlighted only a few of the operations-enhancing technologies identified during the OEPSS study.

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| 49 | GRAPHIC 5-12A | Other operations technologies identified in the OEPSS study with great potential for increasing the operational efficiency of new propulsion system designs include; |
| 50 | GRAPHIC 5-12B | flash boiling and tank pressurization, |
| 51 | GRAPHIC 5-12C | no-leakage mechanical joints, |
| 52 | GRAPHIC 5-12D | differential throttling, |
| 53 | GRAPHIC 5-12E | low NPSH pump, |
| 54 | GRAPHIC 5-12F | wide flow range pump, |
| 55 | GRAPHIC 5-12G | hermetically sealed inert engine, and |
| 56 | GRAPHIC 5-12H | an automated self-diagnostic condition monitoring system. |
| | | DISSOLVE TO: |
| 57 | GRAPHIC 6-1<br>OPERATIONALLY EFFICIENT<br>DESIGN CONCEPTS | |

SEGMENT 6

1 GRAPHIC 6-1
OPERATIONALLY EFFICIENT
DESIGN CONCEPTS

2 LIVE VIDEO?

Our launch experience has shown that the reality of ground processing for flight has fallen short of expectations. The important question is how can this launch experience including the valuable operator's hands-on experience, help make future propulsion systems more operationally efficient? In the OEPSS study, a conceptual design was used to illustrate how a booster propulsion system could be made more operationally simple without compromising performance.

3 GRAPHIC 6-2

For this study, a typical cryogenic advanced launch system consisting of a core vehicle and a booster which can deliver a 120,000 pound payload to low earth orbit was selected.

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| 4 | GRAPHIC 6-3 | The booster contains seven liquid oxygen/liquid hydrogen engines. The core contains three engines. These conventional engines are separate and autonomous. Each engine contains a complete duplicate set of components and sub-systems to function as independent units. |
| 5 | GRAPHIC 6-4A | The booster is a conventional configuration containing the following number of basic elements. |
| 6 | GRAPHIC 6-4B | Fourteen flexible propellant lines, |
| 7 | GRAPHIC 6-4C | fourteen hydraulic actuators, |
| 8 | GRAPHIC 6-4D | fourteen turbopumps, |
| 9 | GRAPHIC 6-4E | seven helium pressurization systems, |
| 10 | GRAPHIC 6-4F | seven GOX heat exchangers, |
| 11 | GRAPHIC 6-4G | and seven control/avionics. The large number of components, subsystems and system interfaces that must be serviced, maintained, checked and verified for launch would be similar to today's experience. |

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| 12 GRAPHIC 6-4G | A closed compartment and heat shields on a large booster would add further complications to launch operations. Now, instead of looking at a booster using |
| 13 GRAPHIC 6-5 | separate autonomous stand-alone engines, let's examine a design or a concept that considers the booster propulsion system as a single engine. This single engine booster is fully |
| 14 GRAPHIC 6-6 | integrated, avoids major duplications, and uses a minimum of components to provide the total thrust. This illustrative concept utilizes the same basic components or design as on the engines for the conventional booster. The thrust chamber design is the same, and the same basic turbopump design is scaled for twice the thrust. On a conventional booster, the turbopump on a stand-alone engine directly feeds its own thrust chamber. Their location is restricted by engine design. However, in the fully-integrated booster, all turbopumps feed the thrust chambers through a common manifold system. |

The turbopumps are no longer constrained by the engine design. They can be freely located to simplify and optimize the design for operational efficiency. This integrated concept is equally applicable to LOX/Hydro-carbon as well as to LOX/LH2 propellant engines.

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| 15 | GRAPHIC 6-7A | Let's examine the results achieved by the fully-integrated system compared to the conventional cryogenic booster. |
| 16 | GRAPHIC 6-7B | The Helium-pressurization systems, |
| 17 | GRAPHIC 6-7C | GOX heat exchangers, and |
| 18 | GRAPHIC 6-7D | control/avionics are reduced from seven to a minimum of one for a total reduction of fourteen subsystems. The |
| 19 | GRAPHIC 6-7E | propellant lines and the |
| 20 | GRAPHIC 6-7F | turbopumps are reduced from fourteen to eight for a total reduction of twelve major components. In this illustrative |

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| 21 GRAPHIC 6-8A | simplified system, a non-gimbaling booster is used. The core vehicle is used to provide thrust vector control. As a result, |
| 22 GRAPHIC 6-8B | no flexible lines are required and the fourteen complex flexible propellant lines are reduced to eight simpler fixed propellant lines. Also |
| 23 GRAPHIC 6-8C | no gimbal actuators are required. The fourteen gimbal actuators and the |
| 24 GRAPHIC 6-8D | hydraulic systems are eliminated. |
| 25 GRAPHIC 6-8D | A direct propulsion comparison between the fully-integrated booster and the conventional booster systems shows a |
| 26 GRAPHIC 6-9 | fifty percent reduction in major parts. |
| 27 GRAPHIC 6-10 | This occurs even though a redundant helium-supply system, a redundant GOX heat exchanger, and one additional thrust chamber are added to the fully-integrated system. |

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| 28 | GRAPHIC 6-11A | Adding a thrust chamber to the integrated booster and to the integrated core equally spaced circumferentially around the ring manifold achieves the following unique and important advantages. Total commonality and symmetry are achieved between the booster and core relative to the propellant |
| 29 | GRAPHIC 6-11B | feedlines and |
| 30 | GRAPHIC 6-11C | thrust structure. A special feedline to a |
| 31 | GRAPHIC 6-11D | center engine is eliminated thereby eliminating a potential POGO problem in the center engine. |
| 32 | GRAPHIC 6-12A | Perhaps the most important advantage achieved by the added thrust chamber is that it provides the integrated system |

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| 33 | GRAPHIC 6-12B | with robust engine operation. It also offers greater |
| 34 | GRAPHIC 6-12C | operating safety, greater |
| 35 | GRAPHIC 6-12D | engine-out capability, |
| 36 | GRAPHIC 6-12E | and higher system reliability. |
| 37 | GRAPHIC 6-13A | Let's examine the area of engine-out for the integrated system. It is uniquely different from the conventional multiple stand-alone engine system. In the conventional engine system with any component failure, the |
| 38 | GRAPHIC 6-13B | affected stand alone engine shuts down completely. For example, if there is a pump bearing failure, this not only shuts down the turbopump, but it also shuts down the thrust chamber, heat exchanger control system, and all other functioning systems on the engine. In the integrated system, if a |

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| 39 GRAPHIC 6-13C | component fails, the component is isolated by valves. These simple isolation valves allow the remaining components and functioning systems to continue to operate. In effect, we have achieved a simpler component out capability. For example, if a thrust chamber fails, the turbopumps continue to feed all the remaining thrust chambers through the ring manifold. |
| 40 GRAPHIC 6-14A | The integrated system is a robust design because with the added thrust chamber, all thrust chambers only operate at |
| 41 GRAPHIC 6-14B | eight-five percent thrust. The thrust chambers throttle up to |
| 42 GRAPHIC 6-15A | one hundred percent design thrust only if there is a thrust chamber-out condition. Similarly, all turbopumps only operate at |
| 43 GRAPHIC 6-14C | ninety percent speed. The turbopumps will throttle up to |
| 44 GRAPHIC 6-15B | ninety-seven percent speed if there is a thrust chamber out condition |

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| 45 | GRAPHIC 6-16 | and throttle to only ninety-three percent if there is a turbo-pump out condition. |
| 46 | GRAPHIC 6-17 | Only if there are both a thrust-chamber-out and a turbopump-out, will the turbopumps throttle up to |
| 47 | GRAPHIC 6-17 | one hundred percent design speed. |
| 48 | GRAPHIC 6-17A | Illustrated in the turbopump performance map of pressure versus flowrate, are the turbopump nominal operating points, wide operating margin, and safe operating speed. |
| 49 | GRAPHIC 6-17B | The low operating speeds of the turbopumps are similar to those for the F-1 and J-2 engines on the Saturn V vehicle. |
| 50 | GRAPHIC 6-18 | The integrated system also has a high overall engine system reliability because fewer parts and simplicity accrue in its favor. The result being |
| 51 | HIGHLIGHT | 0.993 for the integrated system, versus |

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| 52 | HIGHLIGHT | 0.988 for the conventional seven engine system. Perhaps the most dramatic advantage of the integrated system is the engine-out reliability. For example, with a capability of tolerating both thrust |
| 53 | HIGHLIGHT | chamber-out and turbopump-out, the system reliability for the integrated system is |
| 54 | HIGHLIGHT | 0.999. |
| 55 | GRAPHIC 6-19A | On the other hand, a conventional multiple engine system cannot tolerate an independent loss of both a |
| 56 | GRAPHIC 6-19B | thrust chamber and a turbopump. This condition would be equivalent to a loss of |
| 57 | GRAPHIC 6-19C | two engines, and a mission loss. |
| 58 | GRAPHIC 6-20A | The integrated system also has another attractive feature. The residual liquid hydrogen and liquid oxygen in the |

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| 59 GRAPHIC 6-20B | ring manifolds can be used to provide propellants for auxiliary propulsion, such as orbit maneuvering and reaction control as described earlier in the I-HOT study. Because of total symmetry and commonality of the integrated design, both the booster and core propulsion systems can be synthesized by using a common engine-element. |
| 60 GRAPHIC 6-20C | This element is made up of a set of close-coupled turbopumps and two thrust chambers. Two of these |
| 61 GRAPHIC 6-21 | engine-elements make up the integrated system for the core and four for the booster. |
| 62 GRAPHIC 6-22 | Thus, engine-elements in appropriate numbers can be used to develop launch vehicles to deliver a range of payloads from 60,000 to 260,000 pounds. Moreover, the engine-element approach also has the added attractive potential for reducing propulsion development time and cost. The illustrative integrated design concept has demonstrated the following important results. |

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| 63 | GRAPHIC 6-23A | A simple design will be operationally efficient reducing launch processing time and cost. A design must be made simple from the very |
| 64 | GRAPHIC 6-23B | beginning of the design cycle. |
| 65 | GRAPHIC 6-24A | An integrated design was found to be inherently |
| 66 | GRAPHIC 6-24B | simple, |
| 67 | GRAPHIC 6-24C | operationally efficient, |
| 68 | GRAPHIC 6-24D | robust, and has |
| 69 | GRAPHIC 6-24E | high system reliability. Moreover, the illustrative design concept uses only existing state-of-the-art and no new technology. It has also addressed sixteen of the twenty-five operations concerns identified in the OEPSS study. |
| 70 | GRAPHIC 6-25 | In a launch vehicle, the relative position of the propellant tanks has a large impact on ground operations. |

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| 71 | GRAPHIC 6-26 | Locating the LOX tank forward requires routing long oxygen feedline around the hydrogen tank to reach the engine. This causes serious and complex operations problems. |
| 72 | GRAPHIC 6-27A | The potential for geysering in the oxygen feedline is the most serious concern. If this happens an anti-geyser, |
| 73 | GRAPHIC 6-27B | helium bubbling system, requiring a |
| 74 | GRAPHIC 6-27C | complex system of ground support equipment and personnel will be needed to prevent this problem. |
| 75 | GRAPHIC 6-27D | Long propellant lines make propellant conditioning for engine start more difficult. The long and large diameter feed lines and elevated tank make maintenance, servicing, and checkout more difficult. A long propellant line |
| 76 | GRAPHIC 6-27E | is susceptible to POGO problem and may require adding a POGO-suppressor in the line. |

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| 77 | GRAPHIC 6-28A | Geysering can occur during any stop flow, during propellant loading, after loading, before engine start, and during a hold or pad abort. The geysering phenomenon occurs when any |
| 78 | GRAPHIC 6-28B | heat input, shown as Q, causes a bubble to form and to fill the complete diameter of the line. This bullet shaped bubble is known as a Taylor bubble. |
| 79 | GRAPHIC 6-28C | As heat continues to enter the liquid, the Taylor bubble expands, forcing the liquid back into the tank. |
| 80 | GRAPHIC 6-28D | This can also create a geyser within the tank. |
| 81 | GRAPHIC 6-29A | After the geyser, the line begins to refill with cold liquid from the tank. The downward flow is accelerated as the cold liquid condenses the vapor, reducing the pressure of the vapor. |

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| 82 GRAPHIC 6-29B | When the downward flow of the liquid column at high velocity is halted by a closed valve, a sudden pressure spike, known as a water hammer, is created. The magnitude of the potentially destructive spike depends on line geometry, but should be considered high enough to cause the line to |
| 83 GRAPHIC 6-29C | rupture. |
| 84 GRAPHIC 6-30 | A major improvement in ground operations can be made if the LOX tank is placed aft in the launch vehicle. This will facilitate propellant conditioning, ground servicing and checkout, and it will avoid geysering and POGO. This configuration has flown on Jupiter, Centaur, Saturn SIVB, and Saturn S-II vehicles. |
| 85 GRAPHIC 6-31 | Other tank configurations that will improve ground operations are parallel tanks, similar to Saturn I, |
| 86 GRAPHIC 6-321 | and concentric tanks. |
| | DISSOLVE TO: |
| 87 GRAPHIC 7-1 | |

1 GRAPHIC 7-1

DISSOLVE TO:

2 GRAPHIC 7-1A

An operationally efficient propulsion system not only results in a lower cost launch vehicle, but it will greatly simplify and reduce the cost of operating the launch site and facility.

3 LIVE VIDEO

Here, we see a view of the large complex facility to support ground processing of current launch vehicles. Besides the launch pad, we find specialized facilities to process and checkout propulsion systems. These facilities include a hypergolic processing facility; A solid motor processing facility; and a pneumatic servicing facility. Each of these is a complex facility requiring highly specialized ground support equipment, and dedicated personnel to operate.

4 GRAPHIC 7-3

Schematically, the current launch facility can be represented by the following items. Each item is a complex facility in itself.

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| 5 | GRAPHIC 7-3-1 | Service tower for ground interfaces; |
| 6 | GRAPHIC 7-3-2 | APU for |
| 7 | GRAPHIC 7-3-10 | hydraulic power; |
| 8 | GRAPHIC 7-3-3 | Hydrazine fuel handling; |
| 9 | GRAPHIC 7-3-4 | Gaseous Nitrogen and |
| 10 | GRAPHIC 7-3-4A | Helium for pneumatic actuators and purge, and facilities for |
| 11 | GRAPHIC 7-3-5 AND 6 | liquid oxygen, |
| 12 | GRAPHIC 7-3-7 | liquid hydrogen, |
| 13 | GRAPHIC 7-3-8 | nitrogen tetroxide, and |
| 14 | GRAPHIC 7-3-9 | monomethy-hydrazine. In future launch systems, if the propulsion design is made simpler by integrating components or by applying the technologies, then the facility required to support the launch system will be significantly simpler and more operationally efficient. |

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| 15 GRAPHIC 7-4 | For example, if a launch system can be designed so that |
| 16 GRAPHIC 7-4-4 | gaseous nitrogen is not required, then one of these facilities can be eliminated. This can be accomplished by using an open compartment so that no compartment purging is required and by developing an engine that requires no nitrogen purge. |
| 17 GRAPHIC 7-5 | If the launch system can be designed without a hydraulic system, then other facilities can be eliminated. Deleting the |
| 18 GRAPHIC 7-5-10 | hydraulic system eliminates the need for hydraulic, |
| 19 GRAPHIC 7-5-2 | APU, and |
| 20 GRAPHIC 7-5-3 | hydrazine servicing facilities. A hydraulic system is not needed if electromechanical actuators are used for engine valve control, and if the thrust vector control is accomplished either by electro-mechanical actuators, or by engine differential throttling. |

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| 21 | GRAPHIC 7-6 | If the launch system can be designed with common propellants, then even more costly facilities can be eliminated. Here we see how simple the launch site can become when the same propellants for the main engines are also used for the |
| 22 | GRAPHIC 7-6-8 AND 9 | auxiliary propulsion system, the |
| 23 | GRAPHIC 7-6-5 AND 6 | fuel cells, and to provide oxygen for the |
| 24 | GRAPHIC 7-6-ECLSS | life support system. Another substantial benefit is the elimination of the hazardous operations associated with hypergolic servicing. |
| 25 | GRAPHIC 7-7 | If the launch system can be designed so that |
| 26 | GRAPHIC 7-7-4A | helium is not required, then another facility can be eliminated. This is accomplished by designing a propulsion system which requires electromechanical rather than pneumatically actuated valves, and by designing engines that are pre-inerted and sealed, or do not require a turbopump purge, or operate with self-pressurized propellant tanks. |

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| 27 GRAPHIC 7-8 | Finally, if the launch vehicle can be designed for no pad access necessary, and for rise-off disconnects between vehicle-to-ground interfaces--then the |
| 28 GRAPHIC 7-9 | service tower can be eliminated. |
| 29 GRAPHIC 7-10 | What we have achieved in essence is a greatly simplified operationally efficient launch site capable of quick launch response and low operations cost. |
| | DISSOLVE TO: |
| 30 GRAPHIC 8-1 | |

## SEGMENT 8

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| 1 | GRAPHIC 8-1 | |
| | | DISSOLVE TO: |
| 2 | GRAPHIC 8-2A | In order to avoid complex launch operations and reduce operations cost, there is a need to determine the operability of the flight hardware early in design. Currently there is no quantifiable parameter to evaluate the |
| 3 | GRAPHIC 8-2B | operability of a propulsion design to go along with other parameters defining the basic system such as |
| 4 | GRAPHIC 8-2C | cost, |
| 5 | GRAPHIC 8-2D | performance, |
| 6 | GRAPHIC 8-2E | and reliability. During the OEPSS Study, an attempt was made to develop a technique or a method, such as a figure-of-merit or index to measure the operational efficiency of a system design. |
| 7 | GRAPHIC 8-3A | For example, how easily and readily can a piece of flight hardware be processed for launch from the time it's |

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| 8 | GRAPHIC 8-3B HIGHLIGHT THE WORD RECEIVED | received until the time it's |
| 9 | GRAPHIC 8-3C HIGHLIGHT THE WORD LAUNCH | launched? |
| 10 | GRAPHIC 8-4A | To develop such an index, what better way can there be than for a design to be measured up against launch experience? This index must consider real time ground processing and experience-based timelines, launch delays, specialized equipment and facilities. In other words, the launch operations index defines |
| 11 | GRAPHIC 8-4B | operability in terms of launch |
| 12 | GRAPHIC 8-4C | operations complexity. |
| 13 | GRAPHIC 8-5A | The figure-of-merit that was developed is called the Launch Operations Index or LOI. It defines the operability of a design in terms of a level of operations efficiency. This index can be used to evaluate the operability of a top-level conceptual design to determine the operability of a lower-level, well-defined, detailed system or component design. |

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| 14 GRAPHIC 8-5A AND 8-5B | The numerical value of the Launch Operations Index is similar to reliability or any efficiency. It varies from zero to one. |
| 15 GRAPHIC 8-5C | A LOI of zero would mean the worst system that probably cannot be launched. |
| 16 GRAPHIC 8-5D | A LOI of 1.0 would be a perfect system that could launch itself. |
| 17 GRAPHIC 8-6A | The process for calculating the Launch Operations Index is similar to the Quality Function Deployment or the QFD-House of Quality process for evaluating a product. For example, how well does the |
| 18 GRAPHIC 8-6B | product meet what the customer wants. In the case of a piece of |
| 19 GRAPHIC 8-6C | flight hardware, the customer is the hands-on, launch operator and user. Operability is how well the flight hardware design meets the operator's need for operations efficiency. |

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| 20 | GRAPHIC 8-7 AND 8-8 | The initial step in developing the Launch Operations Index is to convert the experience-based, operations concerns into a series of design features that a new propulsion design can use. For example, the closed aft compartment has been a major operations problem. The compartment configuration as a design feature in a new design must address this problem. |
| 21 | GRAPHIC 8-9 | Then, a list of options for the design feature is developed ranging from completely open to completely closed. The options are rated numerically for operability from one to ten with ten being best. |
| 22 | GRAPHIC 8-8A | Similar to the QFD, A-1 matrix process, all system design features are weighted |
| 23 | GRAPHIC 8-8B HIGHLIGHT | on importance. They are based on experience with operations complexity and the potential for launch delays with ten being most important. The design feature's weighting factors and operability ratings are combined to form the resulting Launch Operations Index or LOI. |

24 GRAPHIC 8-10

The Launch Operations Index, still in a formitive stage, has been a useful tool and discriminator for defining operability. It can be used by a system designer to evaluate design concepts which are not completely defined, or to evaluate detail designs. The Launch Operations Index applied to two propulsion concepts A and B is illustrated. Concept B has a simple design with good operability while concept A has a complex design and poor operability. The Launch Operations Index currently is being expanded and refined. A computer model is being developed to allow operations efficiency to be rapidly determined at any stage of design.

25 GRAPHIC 8-11A

The methodology developed for the Launch Operations Index can also be extended to determine the efficiency of other areas of operations. It can be used for

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| 26 | GRAPHIC 8-11B | development operations, |
| 27 | GRAPHIC 8-11C | test operations, |
| 28 | GRAPHIC 8-11D | ground operations at the launch site, |
| 29 | GRAPHIC 8-11E | in-space operations, and finally, even |
| 30 | GRAPHIC 8-11F | overall mission operations. |
| | | DISSOLVE TO: |
| 31 | GRAPHIC 9-1 | |

## SEGMENT 9

1 GRAPHIC 9-1

DISSOLVE TO:

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| 2 VIDEO | Earlier, we described the complex ground activities associated with preparing a propulsion system for launch. |
| 3 VIDEO | What about space operations? How do we prepare, service, or repair a piece of flight hardware that is thousands of miles away, in a hostile environment, with no infrastructure to lend a helping hand? |
| 4 VIDEO | When we think of space operations, the one overwhelming need most apparent is that these systems are going to have to be simple...a lot simpler than past or present systems. These systems must be made reliable, safe, operations-free, and maintenance-free, both while on the ground and in space. |

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| 5 | GRAPHIC 9-6 | A study of operational issues for space systems was made to see how the design of a space transfer propulsion system can be driven to high operational efficiency, and still meet the mission requirements given by NASA Lewis Research Center. This study looked at the |
| 6 | VIDEO OF THE LEM | lunar module, |
| 7 | VIDEO OF THE SATURN SIVB | the Saturn SIVB, |
| 8 | VIDEO OF THE CENTAUR UPPER STAGE | the Centaur upper stage, and the |
| 9 | VIDEO OF THE ORBITAL MANEUVERING SYSTEM | Orbital Maneuvering system on the Space Shuttle. |
| 10 | GRAPHIC 9-7A | The design study resulted in a highly integrated modular engine for a Lunar Lander that combines as many functions as possible to eliminate redundant systems without compromising performance, safety, and reliability. Similar to the integrated booster engine discussed earlier, |

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| 11 | GRAPHIC 9-7B | this integrated space engine utilizes separate turbopumps to feed propellants to a parallel system of thrust chambers through a common ring manifold. In addition, the reaction control system is integrated with the main propulsion system. |
| 12 | GRAPHIC 9-8A | This propulsion system achieved simplicity and high operational efficiency with fewer components and fewer complex interfaces by |
| 13 | GRAPHIC 9-8B | eliminating hydraulics, |
| 14 | GRAPHIC 9-8C | pneumatics, |
| 15 | GRAPHIC 9-8D | gimbaling, |
| 16 | GRAPHIC 9-8E | helium, and |
| 17 | GRAPHIC 9-8F | hypergolic propellants. |
| 18 | GRAPHIC 9-9A | The space system uses the following design features: |
| 19 | GRAPHIC 9-9B | an electromechanical system for valve actuators and |

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| 20 GRAPHIC 9-9C | differential throttling for thrust vector control. It eliminates hypergolic propellants and helium by using |
| 21 GRAPHIC 9-9D AND 9-9E | GOX and GH2 for reaction control and tank pressurization. The integrated reaction control system eliminates multiple propellants on the vehicle. The tank-mounted pumps are automatically chilled and do |
| 22 GRAPHIC 9-9F | not require preconditioning. The system is an |
| 23 GRAPHIC 9-9G | all-welded design, minimizing leakage and increasing safety. |
| 24 GRAPHIC 9-11 | Simplicity and operational efficiency have also been achieved by a space propulsion design made for the Air Force on an advanced Upper Stage application. |
| 25 GRAPHIC 9-10 | This Integrated Modular Engine, called the IME, has all the operability features previously described for the integrated, lunar lander, propulsion design. |

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| 26 | GRAPHIC 9-10 AND 9-12 | In essence, to achieve maximum operational efficiency in space, the propulsion design must be made simple, reliable, operations free, and maintenance free. It must be designed to operate successfully the first time--everytime. |
| | | DISSOLVE TO: |
| 27 | GRAPHIC 10-1 | |

## SEGMENT 10

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| 1 GRAPHIC 10-1 | |
| | DISSOLVE TO: |
| 2 GRAPHIC 10-2 | One of the major objectives of the OEPSS Study was to initiate a process to provide direct operations feedback of launch experience to design centers. This communication process took the form of operations workshops conducted by the OEPSS Team. |
| 3 GRAPHIC 10-4 | On-site workshops for in-depth discussions and exchange of views were held with ALS vehicle contractors like Boeing Aerospace Company, General Dynamics/Space Systems Division, and Martin Marietta Aerospace Company. One-on-one dialogues formed the basis for a thorough review of current launch experience and the impact of design on launch operations problems and issues. |
| 4 GRAPHIC 10-5 | Similar on-site workshops were also held with ALS engine contractors like Aerojet Techsystems, Pratt and Whitney, and the Rocketdyne Division of Rockwell International. |

5 GRAPHIC 10-3

There were also opportunities to participate in operations panels at industry-wide aerospace symposiums at the University of Alabama, and at the Pennsylvania State University. Throughout the OEPSS Study, the results were reported in briefings to all NASA centers, the Air Force, and the ALS Joint Program office.

DISSOLVE TO:

6 GRAPHIC 11-1

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| 1 | GRAPHIC 11-1 | |
| | | DISSOLVE TO: |
| 2 | LIVE VIDEO OF THE FIVE VOLUMES COVERS 11-2 | The results of the OEPSS study have been presented in a series of databooks. The highlights presented in this video are found in the Executive Summary Volume. The specific details are covered in volumes one through four. |
| 3 | LIVE VIDEO OF THE VOLUME I COVER 11-3 | Volume one, entitled Generic Ground Operations Data, presents ground processing data generated for a |
| 4 | LIVE VIDEO FROM VOLUME ONE | generic, expendable LOX/LH2 booster and core propulsion systems. This data is considered a highly representative data base and should be a valuable and informative guide to realistic launch processing requirements for propulsion systems. |

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| 5 | LIVE VIDEO FROM VOLUME ONE | The data includes top logic diagrams, process flow, loaded timelines, and manhours for the main propulsion system. This data is also included for the hydraulic, electrical, and thermal control subsystems. Processing data for tankage and vehicle rollout, launch and scrub-turnaround are also presented. |
| 6 | LIVE VIDEO OF THE VOLUME II COVER 11-6 | Volume two is entitled Ground Operation Problems . This volume includes a |
| 7 | LIVE VIDEO FROM VOLUME TWO | detailed analysis of twenty-five major operations problems and issues encountered at the launch site. These problems and issues apply to both the expendable and the reusable launch vehicles. Operational impact, potential solutions, and technology recommendations are presented. |
| 8 | LIVE VIDEO OF THE VOLUME III COVER 11-8 | Volume three is entitled Operations Technology. |

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| 9 | LIVE VIDEO FROM VOLUME THREE | It presents a list of technology developments that will simplify the operational requirements for new propulsion system designs and increase the operational efficiency of future launch systems. |
| 10 | LIVE VIDEO FROM VOLUME THREE | Also illustrated are the operations problems that would be addressed by each technology, and |
| 11 | LIVE VIDEO FROM VOLUME THREE | how these technologies may be applied to future launch systems and space transfer systems. |
| 12 | LIVE VIDEO OF THE VOLUME IV COVER 11-12 | Volume four is entitled OEPSS Design Concepts. By way of illustrative design, this fourth volume describes how operations efficiency for a propulsion system can be achieved during conceptual design. The fully integrated booster engine and the LOX tank aft concepts have been described earlier in the video. |

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| 13 GRAPHIC 11-13 | A third operational efficient concept is the air-augmented, rocket engine nozzle, after-burning concept. This booster propulsion concept has the obvious advantage of using atmospheric air for thrust augmentation during boost. This reduces the amount of liquid oxygen that needs to be carried on board the launch vehicle and, therefore, reduces the large liquid oxygen servicing required on the ground. If the thrust augmentation obtained can reduce a multistage vehicle to a single stage vehicle, the doubling and tripling ground operations required for multistage vehicles will be avoided. |
| 14 GRAPHIC 11-14 | Based on past studies and present state-of-art, a simple, fixed geometry, ejector/rocket booster was found to achieve significant thrust and payload increases and would be a viable, operationally efficient propulsion concept. |
| 15 LIVE VIDEO OF THE VOLUME V COVER 11-15 | The final volume summarizes the database and results generated by the OEPSS study. |

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| 16 | LIVE VIDEO FROM VOLUME FIVE | The foreword to this volume written by NASA'S study manager provides a clear perspective on our space efforts to date. It also describes the challenges of tomorrow's propulsion technology as it relates to environmental issues and the maximum use of resources.<br><br>DISSOLVE TO: |
| 17 | GRAPHIC 12-0 | |

**SEGMENT 12**

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|---|---|---|
| 1 | GRAPHIC 12-0<br>A GRAPHIC NEEDS TO BE CREATED WITH THE WORDS SUMMARY | |
| 2 | GRAPHIC 12-1A | During this video, we have highlighted the results of the OEPSS study. |
| 3 | PAUSE AUDIO | This comprehensive operations study has identified problems and cost-drivers encountered during ground processing of launch systems. |
| 4 | PAUSE AUDIO | It has also created a data base of launch experience. |
| 5 | PAUSE AUDIO | This data base in the form of databooks will be a useful operations guide for designers. |
| 6 | PAUSE AUDIO | A Launch Operations Index--L.O.I was also developed during this study to provide a long needed quantitative tool to measure operability in a design. A computer model is being developed to provide a more refined method for calculating the Launch Operations Index. From this study. we have also concluded that it is essential for launch operations to be an integral part of the design cycle. |

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| 7 | PAUSE AUDIO GRAPHIC 12-1 | The real key to operability and operations efficiency is...make the design simple! We must reduce the number of parts, systems, and functions as much as possible. Perhaps the |
| 8 | GRAPHIC 12-2A | bottom-line is not to achieve operations efficiency simply to reduce operations cost. If a part or a system can be judiciously eliminated, this will reduce |
| 9 | GRAPHIC 12-2C | time and cost all the way up the line through the whole design cycle. From the designers to the builders--from testing to qualifying--from the installation to servicing, and finally to the launch and flight: All of these areas will reduce time and costs. If a part or a system is eliminated from any of these areas, the |
| 10 | GRAPHIC 12-2B | payback in total cost savings can be exponential! |

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# REPORT DOCUMENTATION PAGE

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This document is a collection of technical data books on several tasks of study during a two year extension to the basic Operationally Efficient Propulsion System Study (OEPSS) conducted by Rocketdyne Division, Rockwell International for the NASA at Kennedy Space Center (KSC), Florida. This document is organized in the following data books: Volume VI, Space Transfer Propulsion Operationally Efficient Study Task of OEPSS; Volume VII, Launch Operations Index (LOI) Design Features and Options; Volume VIII, Integrated Booster Propulsion Module (BPM) Engine Start Dynamics; Volume IX, Preliminary Development Plan for an Integrated Booster Propulsion Module; Volume X, Air Augmented Rocket Afterburning; and an OEPSS Final Briefing/Report along with an OEPSS Video Script with Video.

* Block 4 Con't: Vol X, Air Augmented Rocket Afterburning; OEPSS Final Briefing/Report; OEPSS Video Script with Video

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