SPACE SHUTTLE REACTION CONTROL SYSTEM REQUIREMENTS

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ABSTRACT

THE OPTIMUM REACTION CONTROL SYSTEM IS THE ONE WHICH WILL PROVIDE ADEQUATE OVERALL PERFORMANCE AND SIMULTANEOUSLY RESULT IN THE MAXIMUM VEHICLE PAYLOAD CAPABILITY. THIS REQUIREMENT IS IN MOST CASES SATISFIED BY THE SUBSYSTEMS CONCEPTS (INJECTION PROPULSION, ORBIT MANEUVERING PROPULSION, RCS, ETC.) WHICH COLLECTIVELY RESULT IN THE LOWEST TOTAL VEHICLE WEIGHT. THIS PAPER NOT ONLY DEALS WITH THE TANGIBLE SHUTTLE VEHICLE RCS REQUIREMENTS WHICH HAVE ALREADY BEEN IDENTIFIED OVER THE PAST YEAR (SUCH AS ACCELERATIONS, TOTAL IMPULSE, THRUST LEVELS, ETC.), BUT ADDRESSES ITSELF, AS WELL, TO THE ADVANTAGES OF SOMEWHAT INTANGIBLE REQUIREMENTS WHICH ARE NOT READILY APPARENT TO THE UNINITIATED OBSERVER.

GENERAL REQUIREMENTS

THE ONLY REAL TANGIBLE REQUIREMENT THAT CAN BE GENERALLY SPECIFIED FOR THE RCS OF AN EARTH TO ORBIT SPACE SHUTTLE CRAFT IS THAT IT BE DESIGNED SO AS TO PROVIDE ADEQUATE VEHICLE CONTROL IN ALL 3 AXES, BOTH ROTATIONAL AND TRANSLATIONAL. THE DESIGN SHOULD BE SUCH THAT IT WILL TEND TO MAXIMIZE THE PAYLOAD CAPABILITY FOR A WIDE RANGE OF AS YET UNIDENTIFIED MISSIONS, AT A REASONABLE COST, YET BE SIMPLE AND HIGHLY RELIABLE.

THE OVERALL GOAL, RELATIVE TO THE SPACE SHUTTLE RCS, IS TO PROVIDE A SYSTEM WHICH POSSESSES ADEQUATE OVERALL PERFORMANCE AND RESULTS IN MAXIMUM PAYLOAD CAPABILITY AND MISSION FLEXIBILITY FOR ANY SELECTED VEHICLE CONFIGURATION. THESE GOALS, OF COURSE, MUST BE ACCOMPLISHED WITHIN THE CONSTRAINTS OF A SAFE CREW RETURN AND MINIMUM COST. THE KEY REQUIREMENT, FOR ALL SHUTTLE SUBSYSTEMS, WILL BE TO PROVIDE MAXIMUM MISSION FLEXIBILITY. THIS WILL BE REQUIRED IN ORDER TO FLY A BROAD RANGE OF MISSION PROFILES AND ACHIEVE MAXIMUM COST EFFECTIVENESS FOR THE SPACE SHUTTLE PROGRAM. IN CONTRAST, IN THE APOLLO PROGRAM, THE RCS REQUIREMENTS ALSO INCLUDED FLEXIBILITY TO OPERATE OVER A RANGE OF CONDITIONS (i.e., DUTY CYCLES, PRESSURES, TEMPERATURES, ETC.); HOWEVER, THE DESIGN REFERENCE MISSION WAS FIXED AND REMAINED FIXED FOR ALL LUNAR LANDING MISSIONS. THIS RESULTS IN A VEHICLE WHICH CAN REQUIRE MAJOR HARDWARE MODIFICATIONS IN ORDER TO PERFORM OTHER MISSION PROFILES. THIS BECOMES EVIDENT, IF ONE EXAMINES THE EXTENSIVE MODIFICATIONS REQUIRED TO THE APOLLO COMMAND MODULE AND SERVICE MODULE IN ORDER TO BE COMPATIBLE WITH THE RELATIVELY SIMPLE MISSION PROFILES TO BE FLOWN ON THE SKYLAB PROGRAM.

THE SHUTTLE VEHICLE MUST BE A WORKHORSE OF THE SPACE PROGRAM, CAPABLE OF PERFORMING A MULTITUDE OF MISSIONS AND MUST BE ORIGINALLY DESIGNED FOR INHERENT FLEXIBILITY AND MUST NOT REQUIRE MODIFICATION FOR EACH MISSION CATEGORY.

GENERAL REQUIREMENTS

SELECT RCS CONCEPT WHICH POSSESSES ADEQUATE OVERALL PERFORMANCE THAT WILL PROVIDE MAXIMUM PAYLOAD CAPABILITY AND MISSION FLEXIBILITY WHILE MEETING THE RELIABILITY REQUIREMENTS FOR CREW SAFETY AT A REASONABLE OVERALL COST.

OPERATING CHARACTERISTICS

ONE OF THE MOST SIGNIFICANT CHALLENGES IN THE SHUTTLE RCS AREA WILL BE THE DESIGN OF A TOTAL SYSTEM WHICH WILL BE ABLE TO SAFELY OPERATE OVER AN EXTREMELY WIDE RANGE OF INPUT AND OPERATIONAL PARAMETERS. THE RCS MUST BE CAPABLE OF RESPONDING TO ANY DUTY CYCLE FROM MULTIPLE-MINIMUM-IMPULSE-BITS TO STEADY-STATE FIRINGS OF EXTENDED DURATION WHICH CAN BE RECEIVED FROM THE GUIDANCE SYSTEM. IT MUST BE CAPABLE OF OPERATING OVER A WIDE RANGE OF TEMPERATURES AND PRESSURES. FOR EXAMPLE, THE DENSITY OF THE PROPELLANTS, JUST DUE TO THE EFFECTS OF TEMPERATURE, WILL VARY IN EXCESS OF 100 °/o. SIMILAR EFFECT ON PRESSURE CAN BE EXPECTED DUE TO MULTIPLE ENGINE FIRINGS AND THE INERTIA OF THE FLOW CONTROL EQUIPMENT. OXYGEN TO FUEL RATIOS, THRUST LEVELS AND COOLING MARGINS CAN ALSO BE EXPECTED TO VARY ACCORDINGLY.

THESE REQUIREMENTS, TYPICAL FOR ALL ATTITUDE CONTROL SYSTEMS, CAN RESULT IN SIGNIFICANT CONCESSIONS IN TERMS OF STEADY-STATE AND PULSE MODE PERFORMANCE IN ORDER TO ACHIEVE SATISFACTORY ATTITUDE CONTROL CHARACTERISTICS, HIGH RELIABILITY, AND LONG LIFE. AS AN EXAMPLE THE SERVICE MODULE AND LUNAR MODULE RCS ENGINES WOULD BE CAPABLE OF EXCEEDING 95 °/o C* EFFICIENCY IF THEY WERE DESIGNED TO ONLY OPERATE STEADY-STATE; HOWEVER, IN ORDER TO MEET PULSE MODE AND DUTY CYCLE CONSTRAINTS WITH SUFFICIENT MARGIN TO MAINTAIN HIGH RELIABILITY THE ENGINES ARE OPERATED AT A C* EFFICIENCY OF ONLY 85 °/o.

ALSO, SINCE THE RCS IS A CREW SAFETY SYSTEM, IT MUST BE CAPABLE OF OPERATING SAFELY AFTER INCURRING FAILURES. REDUNDANCY FOR THE PURPOSE OF CREW SAFETY IS NECESSARY; HOWEVER, THE PHILOSOPHY OF REDUNDANCY FOR THE PURPOSE OF MISSION SUCCESS MUST BE CAREFULLY CONSIDERED BEFORE INDISCRIMINATELY GROUNDRULING MULTIPLE COMPONENTS. AS AN EXAMPLE, IT WOULD BE RIDICULOUS TO REDUCE THE PAYLOAD CAPABILITY OF THE SHUTTLE, BY SEVERAL THOUSAND POUNDS, FOR ITS 100 MISSION LIFE IN ORDER TO SUSTAIN AN OPERATIONAL FAILURE, IF THE PROBABILITY OF IT OCCURRING IS VERY REMOTE.

OPERATING CHARACTERISTICS

- RCS MUST BE CAPABLE OF RESPONDING TO ANY INPUT FROM GUIDANCE SYSTEM.
- RCS IS A CREW SAFETY SYSTEM; THEREFORE, IT MUST BE CAPABLE OF OPERATING SAFELY AFTER INCURRING FAILURES. JUDGEMENT MUST BE APPLIED TO PHILOSOPHY RELATIVE TO REDUNDANCY.
- RCS MUST BE CAPABLE OF OPERATING SAFELY OVER TOTAL RANGE OF PRESSURES AND TEMPERATURES.

CONTROL REQUIREMENTS

THE VEHICLE MANEUVERING REQUIREMENTS FOR LINEAR AND ANGULAR ACCELERATIONS ARE NOT TOTALLY AGREED UPON AT THIS TIME AND DEPENDS TO A LARGE EXTENT ON VEHICLE CONFIGURATION; HOWEVER, IT IS APPARENT THAT ANGULAR ACCELERATIONS COMPARABLE TO THOSE USED ON PREVIOUS MANNED SPACECRAFT WILL NOT BE POSSIBLE. INSTEAD, IT IS PROBABLY THAT THE SHUTTLE MANEUVERING RATES WILL BE DETERMINED BY THE MINIMUM ALLOWABLE RATES, IN TERMS OF HARDWARE SENSING LIMITATIONS, RATHER THAN PILOT PREFERENCE BASED ON "FEEL" AS HAS BEEN DONE IN THE PAST.

THE MINIMUM ALLOWABLES FOR NOMINAL ANGULAR ACCELERATIONS, FOR ENTRY, HAVE SETTLED AT APPROXIMATELY 2 $^{\circ}/sec^2$ FOR THE PRIMARY MANEUVERING AXIS (YAW) AND 1 $^{\circ}/sec^2$ FOR PITCH AND ROLL. THE MINIMUM ALLOWABLE LINEAR ACCELERATION, FOR TERMINAL RENDEZVOUS, ARE APPROXIMATELY 0.5 ft/sec^2 FOR THE $\pm X$ DIRECTION AND 0.2 FOR LATERAL AND VERTICAL TRANSLATION. EMERGENCY LEVELS ARE CONSIDERED TO BE SOMEWHERE BELOW THE ABOVE LEVELS, BUT CANNOT BE ACCURATELY DETERMINED WITHOUT CONSIDERABLE SIMULATION STUDIES.

OTHER RCS REQUIREMENTS CONSIDERING THRUST LEVELS, ENGINE LOCATIONS, NUMBER OF ENGINES, TOTAL IMPULSE, AND MINIMUM IMPULSE BITS, ARE EXTREMELY SENSITIVE TO CHANGES IN VEHICLE CONFIGURATION AND REFERENCE MISSION. ONE FACTOR TO REMEMBER; HOWEVER, IS THAT THRUST LEVELS, NUMBER AND LOCATION OF ENGINES HAVE TO BE CONSIDERED CONCURRENTLY IN ORDER TO SATISFY REDUNDANCY, SAFETY AND SATISFACTORY MANEUVERING RATES WHILE MINIMIZING SYSTEM WEIGHT BY REDUCING THE NUMBER AND THRUST LEVEL OF ENGINES TO THE ABSOLUTE MINIMUM. THE LOCATION, SIZE AND NUMBER OF ENGINES IS EXTREMELY IMPORTANT WHEN CONSIDERING EFFICIENT UTILIZATION OF PROPELLANTS FOR MANEUVERING AND ATTITUDE CONTROL. THE TOTAL IMPULSE WILL BE IN THE 1.5 MILLION LB-SEC RANGE WITH THRUST LEVELS FROM 500 TO 2000 LBS DEPENDING ON VEHICLE CONFIGURATION, REDUNDANCY REQUIREMENTS AND SCIENTIFIC NEEDS.

A FEW WORDS SHOULD ALSO BE MENTIONED ABOUT THE PURPOSE OF THE SHUTTLE. MOST EFFORT IS DIRECTED TOWARD THE "DESIGN REFERENCE MISSION" FOR SPACE STATION RESUPPLY. THIS IS USEFUL FOR FEASIBILITY STUDIES AND CLOSELY COMPARING THE CAPABILITIES OF VARIOUS SUBSYSTEMS; HOWEVER, IT SHOULD BE REMEMBERED THAT THE SPACE STATION RESUPPLY MISSION IS ONLY ONE OF A WIDE VARIETY OF INTENDED SPACE RELATED MISSIONS. FOR THIS REASON, THE CHOSEN SYSTEMS SHOULD POSSESS THE HIGHEST DEGREE OF INHERENT MISSION FLEXIBILITY WITHOUT LOSS OF PAYLOAD OR INCREASED COMPLEXITY. IN MOST INSTANCES THE INTEGRATION OF SUBSYSTEMS NOT ONLY RESULTS IN INCREASED MISSION FLEXIBILITY BUT IN OVERALL WEIGHT SAVINGS AS WELL.

CONTROL REQUIREMENTS

- ACCELERATION REQUIREMENTS
  - ROLL — $1\ ^{\circ}/sec^2$
  - PITCH — $1\ ^{\circ}/sec^2$
  - YAW — $2\ ^{\circ}/sec^2$
  - $\pm$ X — $.5\ ft/sec^2$
  - $\pm$ Y — $.2\ ft/sec^2$
  - $\pm$ Z — $.2\ ft/sec^2$
- THE FOLLOWING REQUIREMENTS ARE VEHICLE CONFIGURATION AND INTEGRATION SENSITIVE
  - THRUST LEVEL - 500 - 2000 lbs.
  - ENGINE LOCATIONS
  - NO. OF ENGINES
  - TOTAL IMPULSE - 1.5 MILLION lb-sec
  - MINIMUM IMPULSE BIT
    - NOMINAL - $.05 \pm .01\ ^{\circ}/sec$
    - SCIENTIFIC - $.01 - .05\ ^{\circ}/sec$

SYSTEM LIFE REQUIREMENTS

THE SHUTTLE DESIGN GOAL OF 100 MISSIONS OVER A SEVERAL YEAR PERIOD, IS A SIGNIFICANT DIVERGENCE IN DESIGN PHILOSOPHY FROM PREVIOUS MANNED SPACEFLIGHT PROGRAMS AND REPRESENTS A MAJOR CHALLENGE TO SYSTEM AND COMPONENT DESIGNS. FOR EXAMPLE, THE RCS ENGINES MAY BE REQUIRED TO START UP TO 10,000 TIMES PER MISSION. IF THE SAME ENGINES WERE TO BE USED FOR 100 MISSIONS, A USEFUL CYCLE LIFE OF ONE MILLION STARTS WOULD BE REQUIRED. THIS PRESENTS A SIGNIFICANT FATIGUE PROBLEM FOR LIGHTWEIGHT COMPONENTS ESPECIALLY IF ONE CONSIDERS THERMAL EFFECTS FROM EXTREME TEMPERATURES, AND PRESENTLY UNKNOWN EFFECTS OF HIGH TEMPERATURE HYDROGEN EXPOSURE TO MATERIALS USED FOR CONSTRUCTION. THE EFFECTS OF SIGNIFICANT PRESSURE AND THERMAL CYCLING OF HIGHLY STRESSED COMPONENTS (ACCUMULATORS, DISTRIBUTION LINES, TURBINES, HEAT EXCHANGERS, ETC.) EXPOSED TO ABOVE AMBIENT TEMPERATURE HYDROGEN ARE ESSENTIALLY UNKNOWN AND UNPREDICTABLE AT THIS TIME. IT IS KNOWN; HOWEVER, THAT FEW HIGH STRENGTH MATERIALS ARE UNAFFECTED BY HYDROGEN EXPOSURE AT PRESSURES AND TEMPERATURES ABOVE AMBIENT. FOR THIS REASON, SYSTEMS REQUIRING ULTRA-HIGH CYCLE-LIFE AND HOT HYDROGEN EXPOSURE HAVE INHERENTLY FEWER "BUILT-IN" HYDROGEN COMPATIBILITY PROBLEMS WHEN OPERATING AT LOW PRESSURES AND LOW COMBUSTION TEMPERATURES, THAN SYSTEMS OPERATING AT HIGH PRESSURES AND HIGH COMBUSTION TEMPERATURES. THEREFORE, IT MAY BE DESIRABLE TO DESIGN A SYSTEM TO OPERATE AT O/F RATIOS AND PRESSURES THAT WOULD APPEAR TO BE LESS THAN OPTIMUM WHEN VIEWED FROM ENGINE PERFORMANCE OR CONSUMABLES REQUIRED TO MEET A PREDETERMINED TOTAL IMPULSE. IN FACT THE DECREASE IN COMPLEXITY COULD EASILY RESULT IN AN INCREASE IN PAYLOAD.

LIFE REQUIREMENTS

- RCS MUST BE CAPABLE OF OPERATING FOR 100 MISSIONS OVER A SEVERAL-YEAR PERIOD, WITH MINIMUM REFURBISHMENT
- RCS ENGINES CYCLE REQUIREMENT
  10,000 TIMES PER MISSION (NO REFURBISHMENT)
  1,000,000 TIMES TOTAL (MINOR REFURBISHMENT)
- THERMAL CYCLES
- COMPONENT LIFE
- OPERATING
- NONOPERATING

MISSION FLEXIBILITY

THE DESIGN REFERENCE MISSION FOR SPACE STATION RESUPPLY IS BUT ONE OF A LARGE VARIETY OF INTENDED MISSIONS AND IS PRESENTLY BEING USED AS THE BASELINE FOR THE PHASE "B" SPACE SHUTTLE VEHICLE STUDIES. THE IMPORTANCE OF SUCH A REFERENCE MISSION IS NOT QUESTIONED AS A NECESSARY TOOL FOR COMPARISON OF VEHICLES AND SUBSYSTEMS, BUT VEHICLE REQUIREMENTS SHOULD NOT BE MOLDED AROUND A RIGID MISSION PROFILE AT THIS PHASE OF THE SPACE SHUTTLE STUDY. IT SHOULD BE EMPHASIZED THAT THE SPACE SHUTTLE SHOULD BE THE WORKHORSE OF THE FUTURE SPACE PROGRAM AND THAT MISSION FLEXIBILITY WILL DETERMINE THE OVERALL USEFULLNESS AND COST EFFECTIVENESS OF THE SPACE SHUTTLE.

IT IS ANTICIPATED THAT THE SHUTTLE WILL REGULARLY DEPLOY, SERVICE IN ORBIT, AND RECOVER VARIOUS TYPES OF WEATHER, COMMUNICATIONS, SURVEILLANCE, AND EARTH RESOURCE TYPE SATELLITE SYSTEMS. THE SHUTTLE MAY BE REQUIRED TO FLY LONG DURATION MISSIONS, BECOMING A MINATURE SPACE STATION ITSELF FOR SEVERAL CREW MEMBERS. FOR THIS TYPE OF MISSION, VERY LITTLE ΔV MAY BE NECESSARY; WHEREAS EXTREMELY LARGE QUANTITIES OF HYDROGEN AND OXYGEN MAY BE REQUIRED FOR LONG DURATION ATTITUDE CONTROL, SIGNIFICANT ENVIRONMENTAL CONTROL AND POWER GENERATING CAPABILITY. THE TYPE MISSION DESCRIBED ABOVE COULD NOT BE CARRIED OUT BY A SHUTTLE WHICH HAD INDEPENDENT CRYOGENIC STORAGE FOR INDIVIDUAL SUB-SYSTEMS SIZED FOR THE SPACE STATION RESUPPLY MISSION. ON THE OTHER HAND, THE ABOVE MISSION COULD EASILY BE FLOWN BY A SHUTTLE, SIZED FOR THE SPACE STATION RESUPPLY MISSION, WITH AN INTEGRATED PRO-PELLANT SUPPLY. THE ABILITY TO EFFICIENTLY PERFORM SUCH A WIDE VARIATION OF MISSION PROFILES IS POTENTIALLY ONE OF THE MAJOR ADVANTAGES OF THE SHUTTLE OVER PREVIOUS BOOST/SPACECRAFT COMBINATIONS.

MISSION FLEXIBILITY

- DESIGN MISSION IS SPACE STATION RESUPPLY
- MUST ALSO BE CAPABLE OF FLYING OTHER MISSIONS WITHIN LIMITATIONS OF CONSUMABLES
- INTEGRATION OF PROPELLANT STORAGE SYSTEMS
- OPTIMUM OVERALL PROPELLANT UTILIZATION

SHUTTLE DESIGN ALTERNATIVES WHICH INCREASE MISSION FLEXIBILITY AND/OR PAYLOAD

IN OI [illegible] HIEVE MAXIMUM MISSION FLEXIBILITY AND PAYLOAD CAPABILITY, SYSTEM TRADEOFFS MUST BE PERFOR[illegible] OPTIMIZE THE INTEGRATED VEHICLE. SYSTEM INTEGRATION, POTENTIALLY OF ALL CRYOGENICS INTO A COMMON TANKAGE SYSTEM, MINIMIZES PROPELLANT RESIDUALS, PROVIDING FOR THE UTMOST USAGE OF AVAILABLE PROPELLANTS. IT ALSO MINIMIZES PROPELLANT LOADING REQUIREMENTS AND MAKES IT POSSIBLE TO VARY THE AMOUNT OF PROPELLANT USED BY THE OMS, RCS AND APU's FROM MISSION TO MISSION.

SYSTEM INTEGRATION, PARTICULARLY BETWEEN THE RCS AND THE INJECTION TANKS, MAKES AVAILABLE TO THE RCS THE INJECTION SYSTEM RESIDUALS WHICH OTHERWISE WOULD WARM AND VENT TO SPACE. THESE RESIDUALS COULD AMOUNT TO A SIZABLE QUANTITY OF "FREE" PROPELLANT. USAGE OF THE ORBITER INJECTION TANKS AS A LARGE GASEOUS ACCUMULATOR COULD GREATLY SIMPLIFY THE RCS. IT WOULD PROVIDE, AT NO COST TO THE SYSTEM, AN EXISTING ACCUMULATOR, AN ITEM OF SIGNIFICANT WEIGHT SAVINGS. IT WOULD PROVIDE A RESERVOIR WHERE OMS BOILOFF AND OMS ENGINE SHUTDOWN RESIDUALS COULD BE STORED FOR FUTURE RCS USE. UNCONTROLLED BOIL-OFF OF THESE GASES WILL OTHERWISE RESULT IN AN INCREASED RCS PROPELLANT REQUIREMENT. INTEGRATION OF SEVERAL SUBSYSTEMS COULD BE MADE ON A COMMON FUNCTIONAL BASIS. REDUNDANT LINE RUNS COULD BE MERGED FOR SEVERAL SYSTEMS BY INCREASING A SINGLE RUN'S CARRYING CAPACITY AND HENCE SAVE ADDITIONAL LINE WEIGHT. INTEGRATION OF SYSTEMS OFFERS MANY POTENTIAL OPTIMIZATIONS FOR GREATER MISSION FLEXIBILITY AND GREATER PAYLOAD CAPABILITY.

SHUTTLE DESIGN ALTERNATIVES WHICH INCREASE MISSION FLEXIBILITY AND/OR INCREASE PAYLOAD

- INTEGRATION OF CRYO STORAGE SYSTEM
- UTILIZE INJECTION SYSTEM RESIDUALS
- UTILIZE OMS BOILOFF AND RESIDUALS (BOILOFF VENTING RESULTS IN INCREASED RCS REQUIREMENTS UNLESS CAREFULLY CONTROLLED)
- COLLECTIVE PROPELLANT UTILIZATION
- UTILIZE MAJOR COMPONENTS FOR MULTI-SUBSYSTEM FUNCTION

COST EFFECTIVENESS

TO A LARGE EXTENT, THE COST EFFECTIVENESS OF THE SHUTTLE WILL BE DETERMINED BY THE VERSATILITY INHERENT IN THE SHUTTLE SUBSYSTEMS AND THE RANGE OF SPACE MISSIONS THAT CAN BE EFFICIENTLY PERFORMED WITHOUT MAJOR MODIFICATIONS. IN ADDITION TO THE ABOVE, THE COST EFFECTIVENESS OF THE SHUTTLE CAN BE ENHANCED BY SELECTION OF SUBSYSTEMS WHICH OFFER INHERENT SIMPLICITY OF OPERATION AND THE MINIMUM NUMBER OF ACTIVE COMPONENTS. NOT ONLY WILL THIS PHILOSOPHY REDUCE THE TECHNOLOGY, DEVELOPMENT, AND END ITEM COSTS; BUT, WILL ALSO MINIMIZE THE REFURBISHMENT COSTS. VERY CLOSE CONSIDERATION MUST BE GIVEN WHEN MAKING SYSTEM SELECTIONS TO INSURE THAT SELECTION OF COMPLEX SUBSYSTEMS, WHEN SIMPLER ALTERNATIVES EXIST, RESULT IN A CORRESPONDING INCREASE IN PAYLOAD CAPABILITY TO JUSTIFY THE ADDED COMPLEXITY AND ASSOCIATED INCREASE IN COST.

ANOTHER AREA OF POTENTIAL COST REDUCTION IS AVAILABLE IN THE AREA OF COMMON TECHNOLOGY AND COMMON USAGE OF COMPONENTS. AN EXAMPLE OF COMMON USAGE, ON THE APOLLO PROGRAM, IS THE SERVICE MODULE AND LUNAR MODULE RCS ENGINE, CERTAIN COMPONENTS AND GROUND SERVICING EQUIPMENT. THIS PHILOSOPHY UNDOUBTEDLY SAVED MILLIONS OF DOLLARS ON THE APOLLO PROGRAM. THE SAVINGS CAN BE EVEN MORE DRAMATIC ON THE SHUTTLE PROGRAM, SINCE MULTIPLE MISSIONS ARE INVOLVED AND ACTUAL REPAIR OF COMPONENTS WILL BE REQUIRED. THE FEWER THE NUMBER OF DIFFERENT TYPES OF COMPONENTS TO BE SERVICED AND REPAIRED, THE FEWER THE NUMBER OF TRAINED PERSONNEL WILL BE REQUIRED TO DO THIS JOB. COMMONALITY MUST HOWEVER BE WEIGHED AGAINST A POTENTIAL PAYLOAD GAIN THAT MAY BE ACHIEVED BY USING DIFFERENT COMPONENTS. FOR EXAMPLE, THE COST, IN TERMS OF PAYLOAD, FOR USING THE SAME ENGINE IN ALL LOCATIONS ON THE ORBITER AND BETWEEN THE ORBITER AND BOOSTER, MUST BE EVALUATED.

COST EFFECTIVENESS

- UTILIZE SIMPLEST SUBSYSTEM CONCEPTS (BE SURE THAT INCREASED COMPLEXITY RESULTS IN CORRESPONDING INCREASE IN PAYLOAD CAPABILITY TO WARRANT THE ADDITIONAL COST AND COMPLEXITY)
- UTILIZE COMMON COMPONENTS AND COMMON TECHNOLOGY BETWEEN SUBSYSTEMS TO REDUCE COST AND INCREASE RELIABILITY
- UTILIZE SUBSYSTEM CONCEPTS WITH MINIMUM COMPONENTS AND CONTROLS

MANAGEMENT REQUIREMENTS

MOST OF THE EMPHASIS TO DATE HAS BEEN AIMED AT ACHIEVING A DESIGN THAT WOULD SATISFY THE REQUIREMENTS OF A "DESIGN REFERENCE MISSION" AND STILL BE COST EFFECTIVE. TO ACHIEVE THIS GOAL THE TOTAL VEHICLE DESIGN MUST BE HIGHLY EFFICIENT. THE PRIMARY EMPHASIS IS THEREFORE TO MAXIMIZE THE PAYLOAD POTENTIAL FROM EACH OF THE VARIOUS SYSTEMS OR SUBSYSTEMS. THIS APPROACH, TO REALIZE THE ULTIMATE, DICTATES THE USE OF INTEGRATED SYSTEMS. IF ALL THE PROPELLANT COULD BE PLACED IN ONE TANK AND ALL THE USERS OF THAT PROPELLANT SHARE THE WEIGHT OF THE PRESSURIZATION AND DISTRIBUTION SYSTEMS A SIGNIFICANT WEIGHT SAVINGS COULD BE REALIZED. TO ACCOMPLISH THIS WILL REQUIRE A TOTALLY DIFFERENT DESIGN AND MANAGEMENT PHILOSOPHY THAN THAT USED ON THE PREVIOUS MANNED SPACE PROGRAM. FIRST THE DESIGNERS AND ENGINEERS MUST BE CONDITIONED TO THINK NOT ONLY IN TERMS OF WHAT IS BEST FOR THEIR RESPECTIVE SYSTEM BUT ALSO WHAT IS BEST FOR THE PROGRAM. IT WILL NO LONGER BE POSSIBLE TO OPTIMIZE OR DESIGN THE BEST SUBSYSTEM, BUT RATHER DESIGN THE BEST COMBINATION OF SUBSYSTEMS. IN FACT EXTREMELY LOW PERFORMANCE OF THE APU OR RCS COMBINED WITH A HIGH PERFORMING OMS OR BOOST ENGINE YET SHARING COMMON COMPONENTS OR TANKS MIGHT WELL RESULT IN GREATER PAYLOAD CAPABILITY THAN THAT OBTAINED FROM OPTIMIZING ALL 3 SYSTEMS INDEPENDENTLY.

INTEGRATION OF SUBSYSTEMS POSES ANOTHER PROBLEM OF PERHAPS EVEN GREATER MAGNITUDE. THAT IS MANAGEMENT. THE CHANCES OF SOMETHING BEING OVERLOOKED IS SIGNIFICANTLY INCREASED. FOR EXAMPLE, DR. GEORGE LOW STATED IN A PAPER ENTITLED "APOLLO SPACECRAFT" PRESENTED AT THE AIAA 6TH ANNUAL MEETING AND TECHNICAL DISPLAY, THAT AN IMPORTANT DESIGN RULE IS TO "MINIMIZE FUNCTION INTERFACES BETWEEN COMPLEX PIECES OF HARDWARE. IN THIS WAY, TWO ORGANIZATIONS CAN WORK ON THEIR OWN HARDWARE RELATIVELY INDEPENDENTLY OF EACH OTHER." WE WILL PROBABLY NOT BE ABLE TO FOLLOW THIS DESIGN RULE IN THE SHUTTLE VEHICLE BECAUSE OF THE FLEXIBILITY REQUIRED. THEREFORE, BOTH THE GOVERNMENT AND INDUSTRY PERSONNEL WILL BE REQUIRED TO CONTINUALLY INSURE THAT THE MANY INTERFACES ARE COMPATIBLE AND THAT SYSTEM INTERACTIONS ARE TOLERABLE. IN ADDITION TO THE MANY INTERFACE PROBLEMS, A SIGNIFICANT INCREASE IN DEVELOPMENT COST CAN BE EXPECTED BECAUSE OF THE COMPLEX TEST PROGRAMS REQUIRED TO VERIFY THE INTEGRITY OF THE TOTAL SYSTEM.

MANAGEMENT REQUIREMENTS

- APOLLO UTILIZED INDEPENDENT SUBSYSTEMS
  - MINIMIZED FUNCTIONAL INTERFACES
  - ALLOWED INDEPENDENT SUBSYSTEM DEVELOPMENT
- SHUTTLE MUST UTILIZE INTEGRATED SUBSYSTEM TO MAXIMIZE PAYLOAD AND PROVIDE REQUIRED MISSION FLEXIBILITY
  - RESULTS IN MANY COMPLICATED SYSTEMS INTERFACES AS WELL AS MANAGEMENT INTERFACES
  - GOVERNMENT AND INDUSTRY MUST CONTINUALLY STRIVE TO INSURE INTERFACE COMPATIBILITY