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HL-20 Operations and Support Requirements for the Personnel Launch System Mission

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The processing, mission planning, and support requirements were defined for the HL-20 lifting-body configuration that can serve as a Personnel Launch System. These requirements were based on the assumption of an operating environment that incorporates aircraft and airline support methods and techniques that are applicable to operations. The study covered the complete turnaround process for the HL-20, including landing through launch, and mission operations, but did not address the support requirements of the launch vehicle except for the integrated activities. Support is defined in terms of manpower, staffing levels, facilities, ground support equipment, maintenance/sparing requirements, and turnaround processing time. Support results were drawn from two contracted studies, plus an in-house analysis used to define the maintenance manpower. The results of the contracted studies were used as the basis for a stochastic simulation of the support environment to determine the sufficiency of support and the effect of variance on vehicle processing. Results indicate the levels of support defined for the HL-20 through this process to be sufficient to achieve the desired flight rate of eight flights per year.

Introduction

THE National Aeronautics and Space Administration has initiated a study of vehicle concepts that can satisfy the needs for the next manned transportation system.[1] One study option is a Personnel Launch System (PLS) which can complement the Space Shuttle mission by serving the role of flying priority missions for delivery of personnel or small payloads to orbit using an expendable launch vehicle. The HL-20 configuration is a lifting-body concept that can fulfill this mission.[2–3] The design focuses on a robust system emphasizing low cost, crew safety, reliability, and high operational efficiency. It uses near-term technology in a reusable configuration designed for ease of access to subsystems as an aid in maintenance and servicing operations. Two contracted studies were performed in order to develop better design detail and to provide assessments of the operational support requirements by companies having experience in this area. An initial contract with Rockwell focused on the design detail and assessment of the support requirements.[4] A more recent feasibility study[5] by Lockheed further enhanced the concept and support definitions and determined the benefits that might be derived by using a "Skunk Works" approach for development and operation.

HL-20 support requirements have been analyzed by comparison with demonstrated support needs of existing systems. The amount of information to directly support the HL-20 comparison has been limited, and much of it is not in a form that can be formally referenced. The Space Shuttle, the X-15, and aircraft systems represent the range of vehicles utilized to define HL-20 support requirements. The Shuttle processing approach is defined in Ref. 6, and additional detail is provided in Refs. 7–9 that describe the manpower and processing times required in the pre-Challenger support environment at the Kennedy Space Center (KSC). The X-15 support requirements appear to be a cross between that required for aircraft and spacecraft. Military aircraft support requirements are described in a large database of information provided by the Air Force's Maintenance Data Collection System to define support for new systems. Methods for analyzing maintenance requirements for new systems based on this information source have been developed and are reported in Refs. 10–11. The Mission Operations process at Johnson Space Center (JSC) was first described in Ref. 12 and more recently in the results of the Mission Operation Efficiency Study (MOES).[13] Two studies[14–15] have addressed the processing times required for various PLS designs in the KSC processing environment. A comparison of the HL-20 support as defined in the contracted studies[4–5] with the X-15 support requirements is provided in Ref. 16.

A clear indication of the operational support requirements is needed to aid in the selection process for new systems. This paper presents an initial assessment of those requirements for an HL-20 reusable spacecraft performing the functions needed to satisfy the PLS mission. The level of design detail available in the conceptual design phase dictated an analysis by comparison, where possible, that is traceable to the support required of existing systems. Otherwise, engineering judgments of those experienced in these operations and support (O&S) areas were used. Since no directly comparable system exists, comparisons were drawn from a wide range of vehicle types. The report covers the complete HL-20 turnaround process (landing through launch) including mission operations but does not address the support requirements of the launch vehicle except for integrated activities. Support is defined in terms of manpower, staffing levels, facilities, ground support equipment (GSE), sparing requirements, and turnaround processing time.

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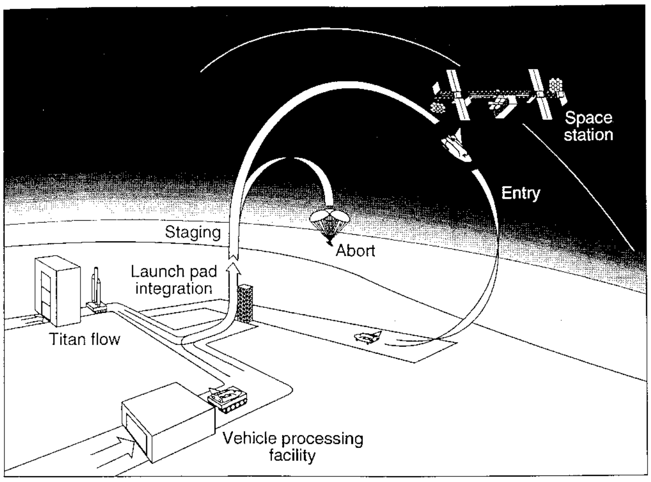

Fig. 1 PLS operations scenario.

Overview of the O&S Environment

The mission scenario envisioned for this vehicle is illustrated in Fig. 1. This primary mission, the Design Reference Mission (DRM-1), is for a nominal mission of up to three days for Space Station crew rotation.[17] The mission assumes KSC as the launch site and the prime site for return. The launch inserts the vehicle into a 100-n.mi. orbit, and the Orbital Maneuvering System (OMS) engines are used to achieve Space Station proximity. Reaction Control System (RCS) burns are used for proximity operations to hard dock with the station. Egress and entry at the Space Station is through an aft located airlock. The HL-20 flight crew is expected to have at least a single sleep period before the return flight. Upon landing at the KSC launch site runway, the vehicle is made safe for processing (safed) and inspected. Then it is transferred to the processing facility where required maintenance is performed to make the vehicle ready for the next flight. The vehicle is then towed to the launch pad where it is mated with the adapter and the launch vehicle. Launch services are performed on the integrated vehicle prior to launch. Mission planning and real-time support are provided for each flight.

One of the most important elements in efficient HL-20 support operations is the turnaround environment that follows its return from flight. This environment incorporates many of the management approaches used in the airline and aircraft industry today as well as approaches being implemented in the current Shuttle program. The maintenance concept is focused on returning the vehicle to a flight readiness state and consists of the following: a complete set of maintenance manuals; a small cadre of technicians with broadly based skills; an integrated maintenance information system that is shared concurrently by all support elements; and full use of timely performance trend analysis data to keep the maintenance program current.

Such a program requires that the O&S concept of the HL-20 be integrated into the design process from the beginning of the program. First the design itself must incorporate maintainability features. Then the test program must be sufficient to provide confidence that design margins will not normally be exceeded. The logistics support program must also be developed concurrent with the vehicle to achieve an operationally viable system. Where possible, hazardous fluids and systems known to require intensive support have been eliminated from this design. The vehicle has been designed for access to the subsystems for ease of maintenance during the turnaround process, for maximum use of health monitoring, and for use of built-in test equipment. Certification of the HL-20 assumes that the vehicle test program was 1) thorough and complete; 2) critical elements were tested to destruction or yield so that their ultimate capabilities were determined; and 3) the flight test program was designed to test the vehicle in excess of its maximum operational envelope, but within its ultimate capabilities. Such a program develops the full confidence necessary to operate the vehicle to its operational limits and, by doing so, reduces the level of inspections required to support the vehicle. The development of the logistics support program concurrent with the vehicle development will allow the implementation of a data acquisition and management information system that can acquire the necessary data on the design and share it with all elements in a timely manner. This also allows development of training and maintenance material directly from the design definition. The mission support process for the HL-20 also shares in this data system to maintain current information on the vehicle as an aid in planning and scheduling. The flight crews fly primarily repetitive missions which minimize their training requirements. Flight planners usually require only updates to support each mission. Based on the described mission scenario and support environment concept, the vehicle, ground, mission, and support requirements are defined in the following discussions.

Vehicle Description

The HL-20 was designed for accessibility to subsystems to simplify the maintenance processes as illustrated in Fig. 2. The design features a pressurized cylindrical crew compartment used to carry the loads transmitted from the unpressurized aeroshell. This design concept provides space for locating subsystems that are easily accessed behind removable panels in the unpressurized areas between the crew compartment and the aeroshell. This allows placement of the subsystems such that removal of one system is not required to access another system. In addition, the vehicle does not contain high-maintenance items such as a main propulsion system or hydraulics. These design features reduce the maintenance time, training, skills, and safety support equipment required for this vehicle.

Ground Operations

The ground operations analysis includes the facility, the processing, and the staffing requirements for these operations. Although several different launch vehicles have been studied for this mission, the Titan concept is the only one described in this paper.

Launch-Site Facilities

The launch, using an expendable Titan launch vehicle, is assumed to be at KSC (Fig. 3). Three new launch facilities were assumed for the HL-20 in addition to the existing Shuttle landing strip at KSC and the Mission Control Center (MCC) at JSC.

A 2300-ft^2 Deservicing and Safing Facility (DSF) was proposed in the Rockwell study to vent and drain any hazardous

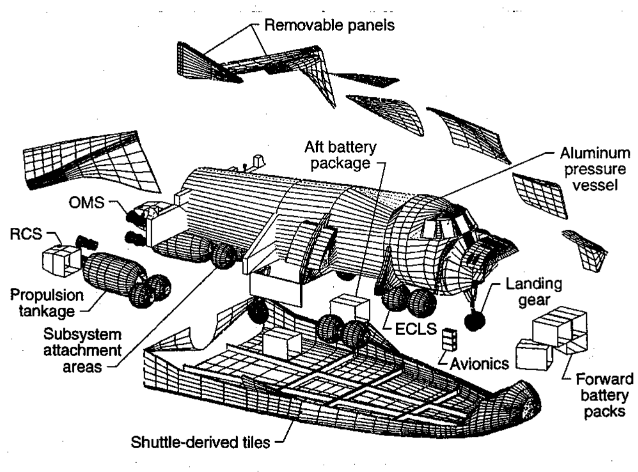

Fig. 2 HL-20 subsystems placement.

liquids and to safe the pyrotechnic devices associated with the landing gear doors and the parachute system. In the Lockheed study, deservicing was completed without the aid of this separate facility. If needed, this facility would be located at the landing strip so that the vehicle would be safed prior to moving to the Horizontal Processing Facility (HPF).

The HPF is designed to be the focal point for all scheduled and unscheduled maintenance activities. This 122,000-ft^2, two-story facility is designed to provide a fully outfitted processing bay for each spacecraft with the flexibility of starting with a single bay and expanding the facility in phases as needed to accommodate additional spacecraft. Each of the high bays used for processing can accommodate a single vehicle, or two if used only for storage. In addition, ample space is provided for parts storage, support shops, and office facilities at this one location.

The Adapter Processing Facility (APF) is a 10,400-ft^2 facility with a high bay designed to receive, assemble, and test the adapter and escape motor system, and with a low bay designed to accommodate office and support areas. This facility will handle hazardous materials so it needs to be located away from other facilities. The full adapter/escape motor assembly is transported to the launch pad for integration to the launch vehicle and the HL-20.

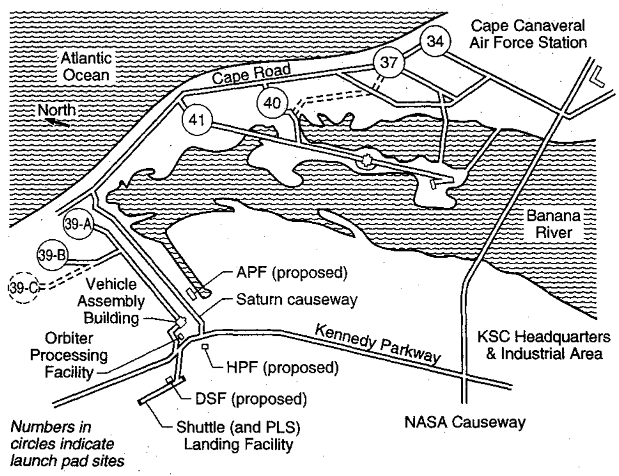

Fig. 3 Launch site geography.

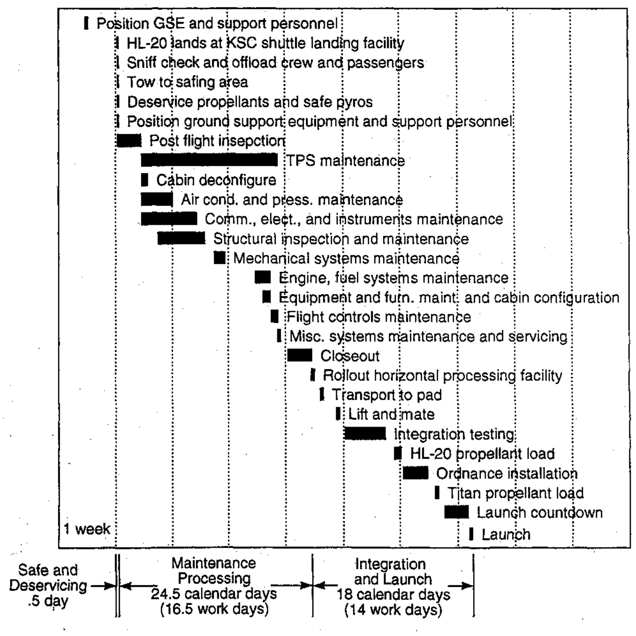

Fig. 4 PLS processing accomplished in 43 calendar days (31 working days, one-shift operation).

Processing

Safe and Deservice

The turnaround process (Fig. 4) begins with the return of the HL-20 to the launch site. The HL-20 lands on the Shuttle landing strip and is towed to the safing facility, where residual propellants from the RCS and OMS are drained and purged. Also the pyrotechnics used by the landing gear and in the chute system are safed. From here the vehicle will be towed to the HPF for maintenance.

Maintenance

The maintenance concept consists of two levels—organizational or vehicle level and depot level. Maintenance in the HPF is primarily organizational. It is driven by a remove-and-replace Line Replaceable Units (LRU) philosophy, with limited repair taking place on the vehicle. The depot level will focus on repair or replacement of the LRUs that are removed and require maintenance. This is discussed in the Support (Logistics) section.

The on-vehicle work uses Airframe and Powerplant (A&P) type technicians, as employed in commercial/civil aircraft maintenance. A&P type refers to certified technicians that are highly skilled and with a broad-based technical background that allows a large amount of cross utilization to take place. This provides maximum use of personnel to perform a range of tasks without requiring specialization in narrowly limited skill areas. A&P type technicians also are allowed to assume some of the quality inspection functions for their own work that might normally require additional inspectors under current Shuttle processing practices. Their work is aided by the use of preplanned maintenance actions that were developed based on a Reliability Centered Maintenance (RCM) analysis. These maintenance instructions are described in the Airline Transport Association (ATA) type manuals for each system. This approach reduces the amount of engineering manpower required for normal maintenance work. The manuals are kept current through the use of an integrated maintenance information system that provides for storing and analyzing all maintenance records and allows timely use of the performance trend analysis data in the maintenance process.

The aircraft maintenance concept that is employed for the HL-20 assumes that the maintenance requirements are primarily driven by the need to repair failed or failing systems in order to restore airworthiness. When the vehicle is received in the HPF, the inspection process that started during deservicing is continued. This process, along with feedback from health monitoring sensors, is used to identify failed systems and those approaching the end of their life expectancy and needing corrective action. The unscheduled maintenance actions are performed to repair or replace these systems only. The level of scheduled maintenance is assumed to be 55% of the unscheduled maintenance, based on aircraft support comparability. Shuttle support requires considerably more scheduled maintenance due to the recertification process that occurs prior to each flight. After vehicle closeout and an integrated systems check, the HL-20 is moved to the launch pad.

Integration & Launch

At the launch pad the HL-20 is mated to the adapter and launch escape system. The personnel to perform integration and checkout operations are drawn from the processing technicians.

The launch operations will be a combined function of the HL-20 support staff and the launch-vehicle support staff. This combined organization will function during the launch phase, with the HL-20 crew resuming full responsibility upon separation from the launch vehicle on orbit.

Table 1 HL-20 maintenance requirements development[a]

ATA no.	ATA system title	Airline data base: MH per flight h	Airline data base: MH per 72 h 1	Launch site adjustment 2	Assumed for HL-20 1 + 2	HL-20 using shuttle methods
21	Air conditioning	0.4126	29.71	193	223	546
23	Communications	0.2508	18.06	24	42	56
24	Electrical power	0.0806	5.80	101	107	159
25	Equipment & furn.	0.1326	9.55	56	66	270
26	Fire protection	0.0476	3.43	0	3	41
27	Flight controls	0.1752	12.61	22	35	257
28	Fuel systems	0.0882	6.35	104	110	129
31	Instruments	0.0034	0.24	20	20	50
32	Landing gear	0.2024	14.57	178	193	230
33	Lights	0.0305	2.20	5	7	17
34	Flight data/mgt	0.2147	15.46	0	15	162
35	Oxygen	0.0328	2.36	16	18	54
38	Water/waste	0.0601	4.33	8	12	54
52	Doors	0.0432	3.11	32	35	299
53	Fuselage	0.0278	2.00	64	66	409
55	Stabilizer	0.0050	0.36	16	16	84
56	Windows	0.0045	0.32	64	64	168
57	Wings	0.0290	2.09	32	34	226
58	Thermal control	0.4668	33.61	232	266	1650
72	Engines	0.2216	15.96	132	148	195
	Total		182	1299	1481	5056

[a]Notes: 1. Reflects processing in horizontal processing facility only.
2. STS orbiter OPF processing required aproximately 34,000 manhours for STS-31.
3. HL-20 requirements are for a typical 72-h mission.

Analysis

Manpower Assessment

The definition of manpower support needs and processing timelines for mature operations focused on the on-line maintenance support of the vehicle systems and subsystems by the A&P type technicians. All other support was keyed off of these personnel. The failure rates for each subsystem were used to drive the maintenance process. Estimates of the failure rates were derived by Rockwell from comparable aircraft subsystems using airline maintenance records for a 747 to provide an airline-based estimate of failure rates for the HL-20. These estimates, shown in Table 1, were provided in the ATA format used by the airlines. The maintenance manhours per flying hour (MH/FH) represent all maintenance work, including both scheduled and unscheduled maintenance generated by all levels of system checks that are performed on the aircraft. These values were then adjusted to the 72-h length of the DRM-1 mission (assuming failure rates are constant over that period). Based on their Shuttle experience, KSC support personnel then modified the maintenance manhour requirements accounting for systems on the HL-20 that had no comparable aircraft system, such as the RCS and OMS, and also for increased support that may be necessary for systems operating in space, such as additional inspections. These results combined for an estimated technician manpower requirement of about 1500 manhours for a typical turnaround operation on the HL-20. This is Rockwell's assessment of the support manpower requirements of the HL-20 if operated using the aircraft maintenance concept as previously described.

As a check on the 747-based estimate of failure rates, Rockwell also developed the same information from their MAtrix database[10] that was based on multiple aircraft data. This approach predicted the same general level of support at the vehicle level, although differing by subsystem. In addition, Rockwell assessed the HL-20 support requirements as if it were to be processed using the Shuttle's support concept. This Shuttle concept emphasizes extensive routine maintenance and testing of all systems; in effect, recertifying the vehicle prior to each new flight. This approach is much different from the airline-based concept in which the aircraft retains its certification until it suffers a failure, and then maintenance processing returns it to a state of airworthiness. Rockwell's assessment using the Shuttle processing approach was over 5000 manhours. This result was similar to the results of a Langley assessment based on Shuttle hands-on processing manpower requirements (Table 2). As noted in the table, this Langley estimate was driven primarily by the differences in size and functional requirements of the Shuttle and the HL-20.

Staffing

Staffing levels were developed from the estimates for technician support. Rockwell used the manpower support estimates based on the failure rates and additional inspection requirements to develop a logical task grouping and sequencing. The manloading for each task was defined based on the time available to perform the task. The HL-20 processing can achieve a flight rate that exceeds the eight flights per year required for the PLS mission (Fig. 5). The staffing level was selected to meet the required flight rate instead of a minimum turnaround time. The tasks were loaded by skill requirements based on the judgement of those familiar with both aircraft and Shuttle processing. The resulting staff consists of 3 avionic, 5 electrical, 11 mechanical, and 3 thermal-protection system technicians. This includes four staffers to process the adapter and accounts for the additional personnel needed to cover the nonproductive time (holidays, sick leave, vacation, etc.). This staff of 22 hands-on technicians working 1 shift, 5-day weeks can be expected to process the vehicle in 31 working days which equates to 43 calendar days. This analysis assumes no modifications or major maintenance during this period. Based on the number of technicians required, the contractor support staff was developed and shown in Fig. 6. This staffing was based on the engineering judgement of the Rockwell team working at KSC and familiar with the Shuttle requirements. The total launch site staff estimate equivalent to the Shuttle Processing Contract (SPC) staffing functions for the Shuttle is 162 people.

Mission Operations

Mission Operations is composed of the processes required to define, prepare, train, and support the PLS DRM-1 mission. The Shuttle mission and flight operations process were

Table 2 HL-20 hands-on manpower requirements based on Shuttle orbiter comparisons[a]

	Vehicle processing time, manhours		
Systems	Shuttle orbiter	Estimated HL-20 lifting body	Decrease for HL-20 compared with shuttle
Quality	1,020	76	944
Integration	186	60	126
Purge, vent & drain	656	164	492
Mechanisms	1,611	86	1,525←No bay
Structures/handling	2,932	460	2,472
Thermal protection system	10,636	976	9,660←Smaller
Main propulsion/SSME	7,012	0	7,012←No SSME
OMS/RCS	1,288	1,288	0
Fuel cell/PRSD	248	248	0
Auxiliary power unit	416	0	416←No APU
Launch accessories	90	32	58
Pryotechnics	292	38	260
Hydraulics	1,045	0	1,045←No hyd
ECLSS	1,724	700	1,024←No WCS
Flight crew	208	112	96
GN&C	780	176	604
Digital	226	88	138
Communications	135	52	83
Instrumentation	76	32	44
Electric power distribution	224	80	144
Software	80	40	40
Cargo bay	3,336	0	3,336←No bay
Total	34,131	4,708	29,519

[a]SSME: Space Shuttle Main Engine; PRSD: Power Reactant Storage and Distribution; hyd: hydraulics; ECLSS: Environmental Control and Life Support System; and WCS: Waste Collection System.

used as a guide for defining the requirements for the HL-20 performing this mission. The tasks and corresponding support required to prepare and support an operational Shuttle mission were first identified by Rockwell for the Space Transportation System Operation Center (STSOC) personnel. This information provided a baseline against which the HL-20/PLS mission was evaluated. Based on this definition the processes, schedules, and personnel required were defined for the Operational Capability Development (OCD) and Orbital Flight Test (OFT) phases that are prerequisites to achieving operational status. Analysis of the manpower required for operational HL-20 missions was then used to define the staffing and mission support timelines.

Analysis of the mission operations includes a description of the Shuttle process, the support assumptions for the PLS mission, discussion of the development phases that lead up to the operational missions, and analysis of the manpower required for operational HL-20 missions that include the staffing and mission support timelines.

Shuttle Process

The Space Transportation System (STS) repeats the flight documentation process for every flight because of the unique mission requirements associated with each flight. The preliminary planning and approval cycle for a Shuttle mission usually begins years before it is to fly. The HL-20 study focused on the planning and design phases captured by the Engineering Production Template (EPT) used to plan the Shuttle missions (Fig. 7). This template captures the STSOC support functions typically performed over the 18- to 20-month period just prior to flight. This is the most manpower intensive period of the mission preparation cycle. These tasks include development of mission definitions, processes, schedules, training, certification of personnel, resource planning, flight products development (reconfiguration of software, flight design, test, verification, and documentation), flight product certification, flight readiness review, and performance of the mission. A Shuttle flight-design process begins with a preliminary flight requirements definition which is used to develop a conceptual level flight profile. This initial process integrates both the trajectory and cargo requirements. These are reviewed and, if satisfactory, a production cycle begins that refines the flight design definition. During this phase, engineering and flight cycles are repeated to produce final flight parameters. Once the flight plan is finalized, the training simulators are reconfigured to support the new mission definition for both flight and cargo handling, and flight training is provided for both crew and mission support personnel. This process is defined by the 91 functions that comprise the EPT. Each of these were reviewed by Rockwell STSOC engineers and modified to meet the HL-20 PLS mission requirements.

PLS Assumptions and Goals

Since the mission is basically the same for DRM-1, the in-depth flight-design process that Shuttle requires on every flight would need to be accomplished only once for the PLS mission, during the OFT phase. Testing during this phase will verify the HL-20 capability and define operational limitations imposed on the vehicle. This repetitive mission allows maximum use of standardized support tools and processes. After the baseline flight design is established, only minor variations

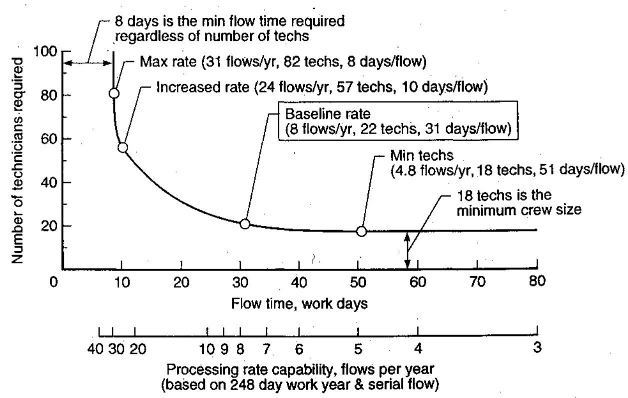

Fig. 5 Technician requirements as a function of launch rates.

because of changing Space Station orbital parameters should be required during mature operations. The groundrules and constraints and the flight rules that govern conduct of flights are developed during the OFT phase and essentially frozen for the operational flights. Both flight crews and ground support personnel will be dedicated to a sufficient number of flights at a frequency that allows the minimum in training time required for recertification.

Development Phases

The final operational support requirements for the HL-20 will be determined by the results of the OCD and OFT phases. The purpose of the OCD phase is to develop the plans and systems required to support the operational missions. Initial program management and control documents were identified in a baseline operations plan, and a schedule prepared for their completion. These documents establish the requirements, roles and responsibilities, and the schedules of the flight operations team. These plans are initiated 30 months prior to and must be completed 13 months prior to initiating the first OFT. The schedule for developing the system tools, the training resources, and the initial OFT are shown in Fig. 8.

The purpose of the OFT phase is to prove the effectiveness of the support systems and methods developed during OCD through progressive flight testing. The OFT phase will be conducted over a period of approximately 15 months. This test phase allows for up to six test flights, including two for contingency. The preparation cycle for the first mission is expected to require 13 months. This is the first full exercise for each system, and allowance is made for additional runs and

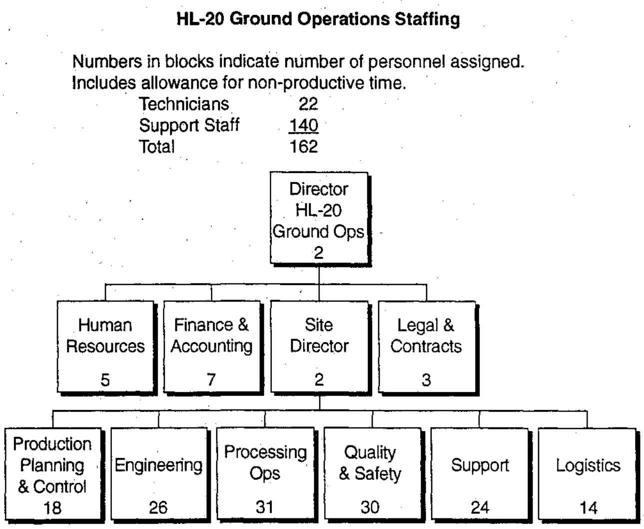

Fig. 6 Launch site staffing.

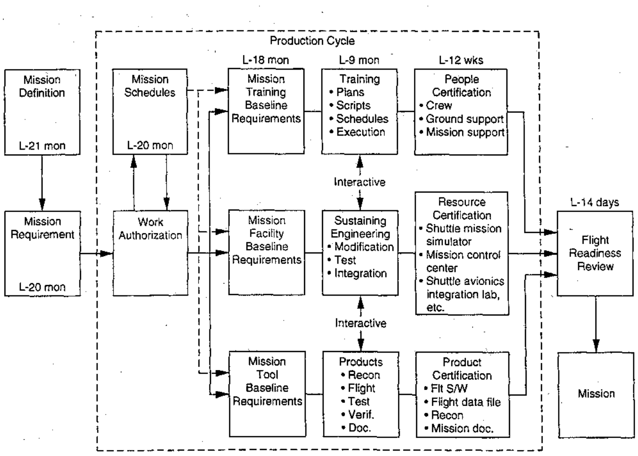

Fig. 7 Shuttle mission engineering production template.

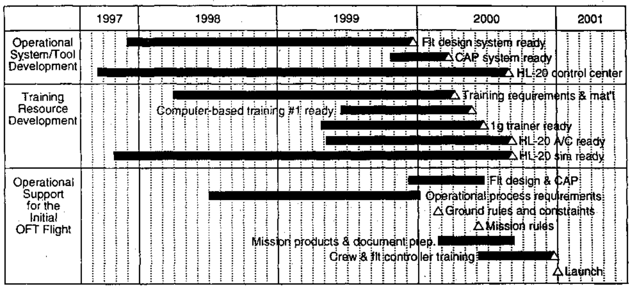

Fig. 8 HL-20 mission operations development.

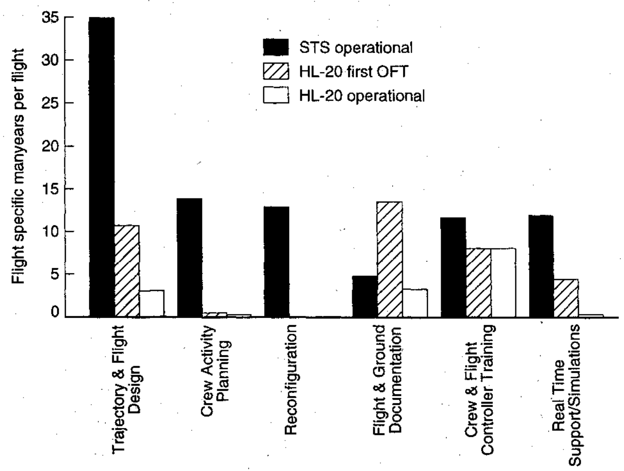

Fig. 9 Mission operations flight-specific manpower comparison/flight.

exercises that might be required to develop the first mission set. The preparation time would be expected to decrease on each succeeding flight down to the 6 months estimated for operational flights. Once operational, the 6-month processing schedule and the support requirements would be expected to remain constant as long as the mission does not change.

Analysis

Manpower Assessment

The manpower, and ultimately the staffing requirements, were primarily derived from the STSOC Time Card database representing typical Shuttle missions. These requirements are defined in terms of flight-specific, all-flight, and nonflight manpower for a single mission. These categories are defined respectively as personnel assigned directly to a Shuttle mission, personnel assigned to the Shuttle program but not to any specific mission, and personnel assigned to the support roles of the STSOC organization. The flight-specific manpower could be further defined according to six major functional areas representing the EPT functions. These are 1) development of trajectory and flight-design data, 2) crew activity planning, 3) reconfiguration of flight software for each mission, 4) development of flight and ground documentation to support the mission, 5) training of support personnel and crews, and 6) real-time support during mission operations. The support requirements were then tailored to match the PLS mission operations based on the Shuttle distribution of these functions. The results of that analysis are shown in Fig. 9 which compares the PLS mission support manpower estimates to the STS requirements for both the first OFT and the operational missions.

These estimates were based on both the reduced functional role (station rotation, no cargo, etc.) of the HL-20 and the repetitive mission that it would fly, which allowed the mission support to be built around this subset of the STS functions. Reconfiguration requirements of Shuttle for each new payload affects the flight software requirements and also drives the amount of flight planning documentation. This reconfigura-

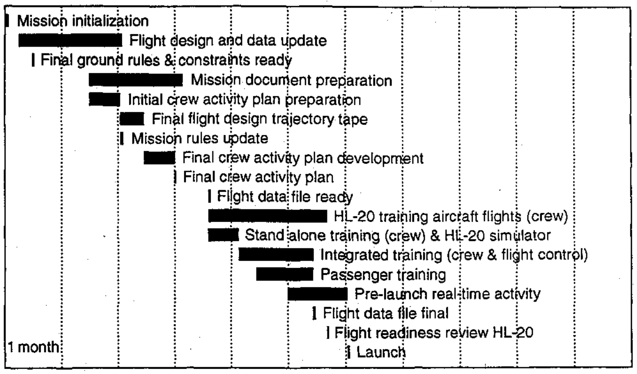

Fig. 10 Schedule for development of operational missions.

tion represents nearly half of the Shuttle EPT functions. Since the HL-20 will normally fly a standardized mission of crew delivery to the Space Station and return with no separate cargo, reconfiguration will not be required, and 60% of these functions can be eliminated or reduced. Of the remaining functions dealing with crew activity planning and training, most will be required only during the OFT phase when the developmental flights occur. The standardization of the flight design after the OFT flights also reduces support for the flight design, crew planning, and the training requirements because of the repetitive nature of the mission. The training requirements will also be reduced through the use of dedicated crews that fly the PLS mission for a series of flights. This will take advantage of the inherent training provided by repeated missions as well as minimizing the need for training new personnel. These reductions result in a schedule for development of operational flights of six months (Fig. 10).

The real-time mission operations tasks are trouble shooting, procedures and timeline support updates, in-flight maintenance support, medical support, and search-and-rescue coordination. The resources needed for the PLS mission can be significantly reduced because of the relatively limited scope of the mission. The real-time support positions for the PLS mission are guidance, navigation, and control (GN&C), flight dynamics officer, systems, propulsion, data processing system, communications, and flight manager. During ascent, docking, and entry flight operations, each position will be supported full time. With the exception of the flight manager and the data processing system monitor, these positions are on-call when docked at the station. These functional areas will be backed up by 24 support personnel located in an adjacent control room.

Staffing Definition

The resulting support manpower requirements were converted into the staffing levels needed on an operational basis. These staffing levels equivalent to STSOC are illustrated in Table 3. A new flight preparation cycle must be started every 6.5 weeks to meet the eight flights-per-year rate. This process requires two mission operations crews to alternate mission assignments for most of the functions in support of this flight rate. Additional functions, such as developing the process requirements and establishing the groundrules and constraints, are repeated on an infrequent basis, and these requirements are assumed to be met within the staffing levels for all other functions.

Support (Logistics)

The support requirements for the HL-20 focused on the off-line maintenance (on-line maintenance is defined in the Ground Operations section). The logistics program is driven by the unscheduled maintenance requirements (Fig. 11) which are defined by the needed resources in terms of spares, support equipment, and technicians. The HL-20 analysis examined and defined the logistics support levels in terms of management, organization and depot maintenance, organization and depot support equipment, spares and consumables, organizational and depot training, depot maintenance manuals, and transportation.

Management

The Integrated Logistic Support (ILS) management is responsible for planning, tracking, and managing the program resources (manpower, flight, and ground resources) over the program life. ILS is assumed to be established early in the HL-20 program so that it can bring O&S considerations into the design process. The management of the logistics support organization was assumed to remain within the KSC infrastructure. Although this is not consistent with the non-embedded support used in the rest of the study, the most economical approach is to merge all functions that are common into one organization and then to use the resources on an as-required basis. For the same reason, no separate facilities were defined for warehousing the spares. The management and support staffing required for the logistics function are included in the support personnel (Fig. 6). Based on the support environment assumptions, the documentation of spares and repair data is accomplished during the design, develop, test, and evaluate (DDT&E) phases.

Maintenance

The ground-based maintenance concept is for a two-level maintenance system—organizational and depot. The organizational level, or on-vehicle level, was primarily oriented toward a remove-and-replace policy at the LRU level. Although minor repairs would take place on the vehicle, the concept is to take full advantage of built-in test equipment and the fault isolation capability to minimize on-vehicle servicing and thus

Table 3 Mission operations staffing

		Headcount			
	MYR	Total	Eng	Tech	Mang
Nonflight	10.47	86			
All flight	7.50	60			
Flight specific	16.99	206	144	48	13
Develop operations process requirements[a]					
Establish flight groundrules and constraints[a]					
Develop mission initialization plans and schedules	1.50	26	18	6	2
Develop initial flight design and data	3.08	31	22	7	2
Prepare crew activity plan	0.38	6	4	1	0
Prepare mission products & documentation	3.38	34	24	8	2
Perform prelaunch real-time support	0.25	4	3	1	0
Perform crew and flight controller training	8.13	72	50	17	5
Real time support/simulations	0.27	33	23	8	2
Total mission operations staff		352			

[a]Functions occur infrequently, manpower requirements assumed handled by other functions.

minimize the impact on the turnaround schedule. Full use of the reliability-centered maintenance approach, both prior to activation and through continuous improvement updating of the maintenance experience, is used to identify the proper maintenance and servicing items.

Support Equipment

Two types of support equipment were defined for the HL-20, GSE, and Automatic Test Equipment (ATE). Over 80% of the GSE was defined in terms of Shuttle equipment that might be applicable to the HL-20. Additional GSE items that are not traceable to historical data were defined for the support environment peculiar to the HL-20. The ATE is necessary to perform repairs on the electrical and avionic systems after they have been removed from the vehicle. These support systems were analyzed based on the equipment currently used in the NASA Shuttle Logistics Depot (NSLD).

Spares and Consumables

The spares estimate is based on the reliability of the equipment and the policy for stocking spares (sparing). The development of spares requirements is based upon the analysis using the Rockwell MAtrix model which predicts spares replacement rates. This sparing policy requires purchase of both the initial and recurring spares in a one-time buy as a part of the manufacturing process for the operational assets. The number of spares required was based upon a 0.95 sufficiency rate to meet the 143 flight program plus up to six OFT flights. Sparing for the expendable elements, the adapters, and the launch escape system will make use of the "piggy-back" sparing process that simply borrows against production requirements. This policy requires production to be sufficiently ahead of demand requirements and minimizes the quantity of spares that must be purchased and stored for expendable hardware.

Training

The training requirements were defined for both the on-line technicians and for those performing the off-vehicle repair. Training requirements were developed for initial, recurring, turnover, and recertification of personnel. These requirements are primarily a function of the number of personnel to be trained and the repair tasks to be performed. The larger number of unique skills and higher complexity of the tasks required, the larger the training requirements.

Manuals

Maintenance manuals are required for technicians executing repairs. The expense for manuals is based upon the development cost and recurring cost updates. Because of the HL-20 maintenance approach and the assumption that the data for the manuals would in part be satisfied by the use of the Computer Aided Logistics System (CALS) data, the average cost should be less than that required for Shuttle.

Transportation

The HL-20 was designed to enhance its ability to be transported without special support aircraft or vehicles. With the fin-folding feature, the vehicle can be carried aboard the C-5A/B, and in the future aboard the C-17. This should make transportation from plant to launch site, and from alternate landing areas, easier than the Shuttle process.

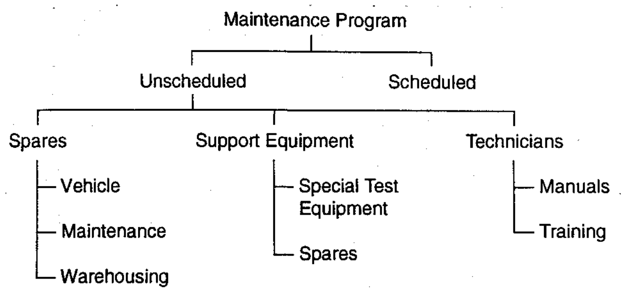

Fig. 11 Logistics is driven by unscheduled maintenance.

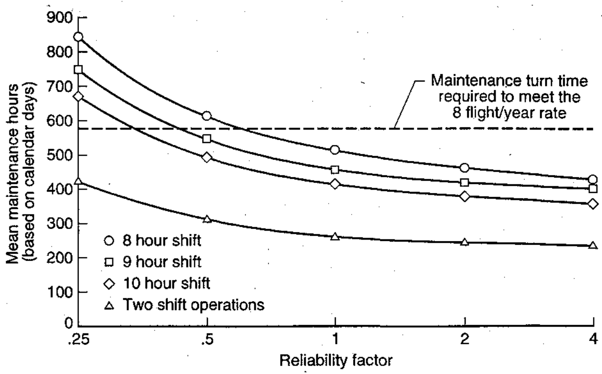

Fig. 12 Mean maintenance turnaround time variability.

Simulation Studies

Simulation studies used the support definitions which are provided in the contracted studies to explore the effects of variability in the processing environment on the manpower and turnaround time requirements of the HL-20. A discrete-event model of the maintenance process was developed for the turnaround activity. No schedule delays, modifications, or major maintenance were considered. The model was based primarily on the maintenance description provided by Rockwell, with the maintenance support crew assumed to be 3 avionic, 5 electrical, 11 mechanical, and 3 TPS technicians. After the postflight inspection was completed, parallel processing was assumed for all maintenance functions. Maintenance crews were drawn from the pool of technicians and were assigned to each support task based on the definition provided. The spacecraft adjustment values, as defined in Table 1 for each subsystem, were considered as scheduled maintenance and were performed as a part of every turnaround operation. The failure rates for each subsystem were based on the mean time between maintenance (MTBM) data provided by the MAtrix model.[10] Failure clocks were set for each subsystem and checked upon landing. Each failure was assigned a support crew based on the type of failure and for a duration based on the number of failures of that system during the mission. The failure rates were assumed to follow an exponential distribution.

Work was divided into on-vehicle, remove and replace, and shop work. Only the on-vehicle and remove-and-replace work were considered as on-line work that impacts the turnaround time. Once removed from the vehicle, a LRU was assigned a support crew for shop repair. Shop work was considered an off-line process affecting the turnaround time only by its demand on the same manpower resource pool as the on-line work. The mean time to repair (MTTR) and variance used in the model were derived from F-15 support requirements[18] and assigned to each repair task based on comparability between the subsystems. These repair times were assumed to follow a log-normal distribution.

The results of simulation studies indicate that processing can be accomplished within schedule 80% of the time using the predicted failure rates. For this nominal case, the use of limited overtime allows 100% of the processes to be completed within the allotted time for these rates. The model results are illustrated parametrically in Fig. 12 which show the mean processing maintenance time predicted for 8-, 9-, and 10-h shifts. Also shown in the figure is the effect of varying reliability factors on the maintenance times. In addition to the baseline level, reliability was addressed at twofold and fourfold increases and decreases. Because of the increase in the number of failures resulting from the twofold and fourfold reliability decreases (reliability factors of 0.5 and 0.25, respectively), overtime and/or additional maintenance crew may be required to meet the flight rate schedule. For all cases, a second shift would meet the requirements.

Discussion of Results

The purpose of analyzing the support requirements from both the airline support approach and the Shuttle approach was to define the maximum reasonable range of support required based upon historical maintenance records of those respective systems. The advantage of this approach is that it captures the total requirements for the design and the operating environments that are characteristic of these systems. These requirements usually exceed the level of support that would be defined based only on the design definition that is available at the conceptual level. The historical records capture the effects of design detail not available at this level. Operations support estimates, from the most optimistic assessment of operating the HL-20 purely as an aircraft to the support provided Shuttle, produce a realistic range for the support manpower requirements that could be expected of this vehicle in an operational mode. The actual support level most likely falls between these extremes, and based on the contractor's experience, the support level will be about 1500 manhours.

The similarity of the HL-20 concept in general size, weight, and subsystem composition to that of the X-15 allowed a comparison of the predicted support manpower and turnaround times with that experienced in the X-15 program. Comparable operations and support information for the X-15 were for a hands-on staff of 12 technicians per shift with broad-based skills operating two shifts per day, 5-days per week typically turning the vehicle around in 13 calendar days or less. This represented a maintenance burden of some 1700 manhours for the X-15 which also includes some burden for modifications and delays. Based on the assumption of comparability between the two systems, the predicted staffing levels, skill mix, and refurbishment times of the operational HL-20 appear to be similar to that experienced by the X-15 for ground support. However, the HL-20 will likely be operating in a different environment than existed at Edwards Air Force Base during the fifties and sixties. Current operational conditions may impose additional requirements on the HL-20 to satisfy safety and environmental regulations that will add to the maintenance and support burden predicted by the X-15 analogy.

The PLS mission has a much reduced set of functional requirements than the Shuttle. One of the primary reasons for the reduced support required of the HL-20 is the smaller number of functions for which it is designed. This smaller role not only reduces the number of mission options that must be prepared for each flight, but also the systems that have to be maintained during turnaround operations. Note that if the mission requirements were changed to include some of the additional functional roles, the support requirements for the HL-20 would most likely increase.

An attempt to define support with the design definition available at the conceptual level introduces a degree of uncertainty in the results. The purpose of defining support at this early stage is to develop reasonable initial estimates of the support requirements based on existing systems. Support definitions are updated and refined as the vehicle definition matures, thus reducing the uncertainty.

Concluding Remarks

The HL-20 represents the next generation of manned reusable spacecraft. To determine the support required for this vehicle to perform the PLS mission, an assessment has been made based upon comparisons with existing systems. Where this comparison was not possible, engineering estimates were obtained from those working in that support area. The maintenance and support concepts, which are used as the basis for the assessments, incorporate applicable aircraft concepts and methods. Although it is recognized that the HL-20 would likely become embedded in an existing support system, an attempt was made in this report to define the support requirements independent of those systems. The assessments are based on vehicle and support technologies available in the operational timeframe.

Since the flight rate is fixed at a maximum that is within the support capabilities, it is not a driver for O&S requirements of the HL-20 flying the PLS mission. The results are representative of the support commensurate with this flight rate. The manpower estimates for the HL-20 turnaround support fall between values that would be expected based on either aircraft or Shuttle flight experience. The manpower, turnaround, and skill requirements appear similar to that experienced in the X-15 flight program. These results appear to confirm the estimated range of support needed for the HL-20 during its mature operational phase.

The results point to the potential saving that can occur if aircraft type operations are achieved for the HL-20. Future studies are needed to gain a better understanding of the difference in maintenance drivers required by the Shuttle and aircraft. However, based on the results of this study, the HL-20 can be processed and supported for the projected flight rate.

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