NASA Technical Memorandum 4453

X-15/HL-20 Operations Support Comparison

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JUNE 1993

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Acknowledgments

This report brings together ideas and information from several individuals without whose comments and insight the study would not have been possible. I wish to thank Charles N. Baker and Jack Kolf of the Dryden Flight Research Facility for reviewing this document and for providing information based on their experiences in the X-15 program critical to completing the study. Additionally, appreciation is extended to Wally Eshleman of the Lockheed Advanced Development Company whose discussions on methods of developing support manpower helped to formulate the comparison approach used in this paper.

Summary

During the 1960's, the United States X-15 rocket-plane research program successfully demonstrated the ability to support a reusable vehicle operating in a near-space environment. The similarity of the proposed HL-20 lifting body concept in general size, weight, and subsystem composition to that of the X-15 provided an opportunity for a comparison of the predicted support manpower and turnaround times with those experienced in the X-15 program. Information was drawn from both reports and discussions with X-15 program personnel to develop comparative operations and support data. Based on the assumption of comparability between the two systems, the predicted staffing levels, skill mix, and refurbishment times of an operational HL-20 appear to be similar to those experienced by the X-15 for ground support. However, safety, environmental, and support requirements have changed such that the HL-20 will face a different operating environment than existed at Edwards during the 1950's and 1960's. Today's operational standards may impose additional requirements on the HL-20 that will add to the maintenance and support burden estimate based on the X-15 analogy.

Introduction

The X-15 rocket-plane program is arguably one of the most successful flight research programs to date. Conceived in the early 1950's, this rocket powered aircraft began flight testing in the late 1950's and concluded in 1968 after 199 flights. The flights were staged from a B-52 aircraft that was used to carry it to launch altitude. The X-15 set speed and altitude marks yet to be surpassed by any other aircraft. While much of the focus of the program was on the scientific and engineering discoveries that increased our knowledge of high-speed aeronautics and technology, the processes needed to support space flight of later reusable spacecraft were being developed by those responsible for servicing the X-15. A number of papers have been written that address the X-15 operational processing (Hoey and Day 1962; Love and Palmer 1961; Love and Young 1965, 1966, and 1967; Row and Fischel 1963). However, detailed information about specific support operations such as the maintenance crew size and skill mix was not generally covered by these reports. The source of that information is retained, primarily, in the memories of those who were a part of the X-15 program. Some of the support methods developed during the program appear to be the basis for techniques still in use in the Space Shuttle program.

The HL-20 represents a recent study of a lifting body concept designed to complement the Shuttle as a means to support Space Station crew rotations on an operational basis (Piland 1990). Required to be launched into orbit by an expendable launch vehicle, the HL-20 would itself be reusable and require a maintenance program to prepare it for reflight. Contracted studies with Rockwell International Corporation (Ehrlich 1991) and later by Lockheed Advanced Development Company (Personal Launch System Feasibility Study under NASA Contract NAS1-18570) further defined the initial NASA concept in terms of subsystem requirements and provided initial estimates of the manpower and processing times required based on aircraft and airline maintenance concepts. From these estimates a comparison can be drawn between the X-15 and the HL-20 concept to assess the potential support requirements of this new system.

The proposed HL-20 design has many similarities to the X-15 (figs. 1 and 2, table I). They are similar in size and weight, they are both staged off of launch vehicles, they both consist of a fleet of 3 aircraft, and they have similar subsystem types, including reaction control, avionics, thermal protection, etc. The flight program for the X-15 lasted over 9 years and included 199 flights. The HL-20 flight program is anticipated to include 143 flights over a 20-year period. Over the life of the X-15 program, the average turnaround time for this research aircraft was 44 calendar days, including mission and delay times (derived from Miller 1983, see appendix). Turnaround time for the HL-20 is predicted to be 46 calendar days, including a 3-day mission.

This paper presents a comparison of the predicted support requirements for the HL-20 with the historical support requirements of the X-15 in terms of manpower and turnaround time. The X-15 requirements were established by drawing from past reports and from interviews with those with firsthand maintenance and support operations experience on the vehicle.

Nomenclature

ac	alternating current
ACC	advanced carbon carbon
AFRSI	advanced flexible reusable surface insulation
Ag-Zn	silver zinc
APU	auxiliary power unit

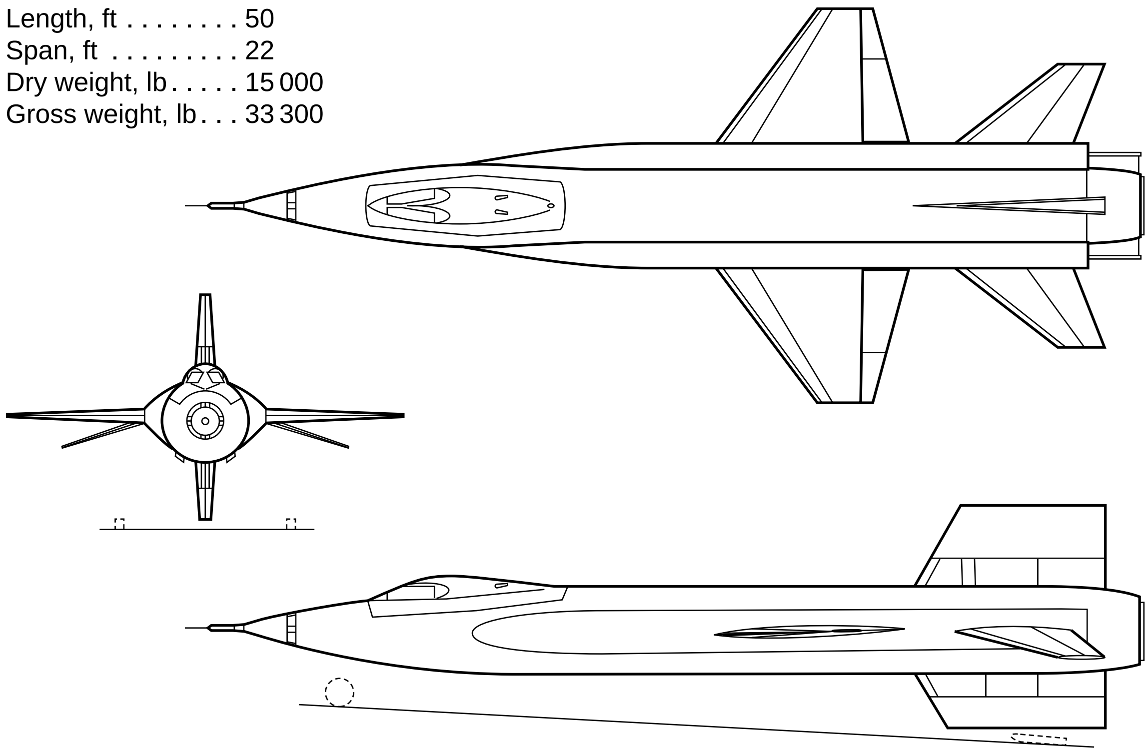

Figure 1. X-15.

A&P	airframe and powerplant
BITE	built-in test equipment
CO_2	carbon dioxide
dc	direct current
ECLSS	environmental control and life support system
GN&C	guidance, navigation, and control
GSE	ground support equipment
HTP	high-temperature performance
HUD	head-up display
KSC	Kennedy Space Center
LiOH	lithium hydroxide
LOX	liquid oxygen
MMH	monomethyl hydrazine
NDE	nondestructive evaluation
N_2O_4	nitrogen tetroxide
OMS	orbital maneuvering system
RCS	reaction control system
STS	space transportation system
TPS	thermal protection system
TVC	thrust vector control

Processing Descriptions

X-15 Turnaround Process

Turnaround time is considered the length of time from the completion of one flight to the completion of the next flight, including ground processing and mission time. The refurbishment or maintenance time, which is a subset of the turnaround time, is measured from the time the vehicle returns from flight to when it is ready for the next flight (Love and Young 1967). Refurbishment time is dependent on the maintenance, instrumentation, and modification requirements; the flight schedule; and the size of the support crew. During the mid-1960's the X-15 program was achieving a flight rate of over 30 per year for the 3-aircraft fleet. According to discussions with Charles N. Baker, former X-15 crew chief at the Dryden Flight Research Facility, in this time period the support crew for each aircraft typically consisted of 12 technicians per shift, 2 shifts per day, 5 days per week. (In the last 2 years of the program, when the flight rate was reduced, a single support crew

	Rockwell design	Lockheed design
Body length, ft	29.5	29.5
Span, ft	23.5	23.5
Dry weight, lb	19 501	19 170
Gross weight, lb	27 915	25 486

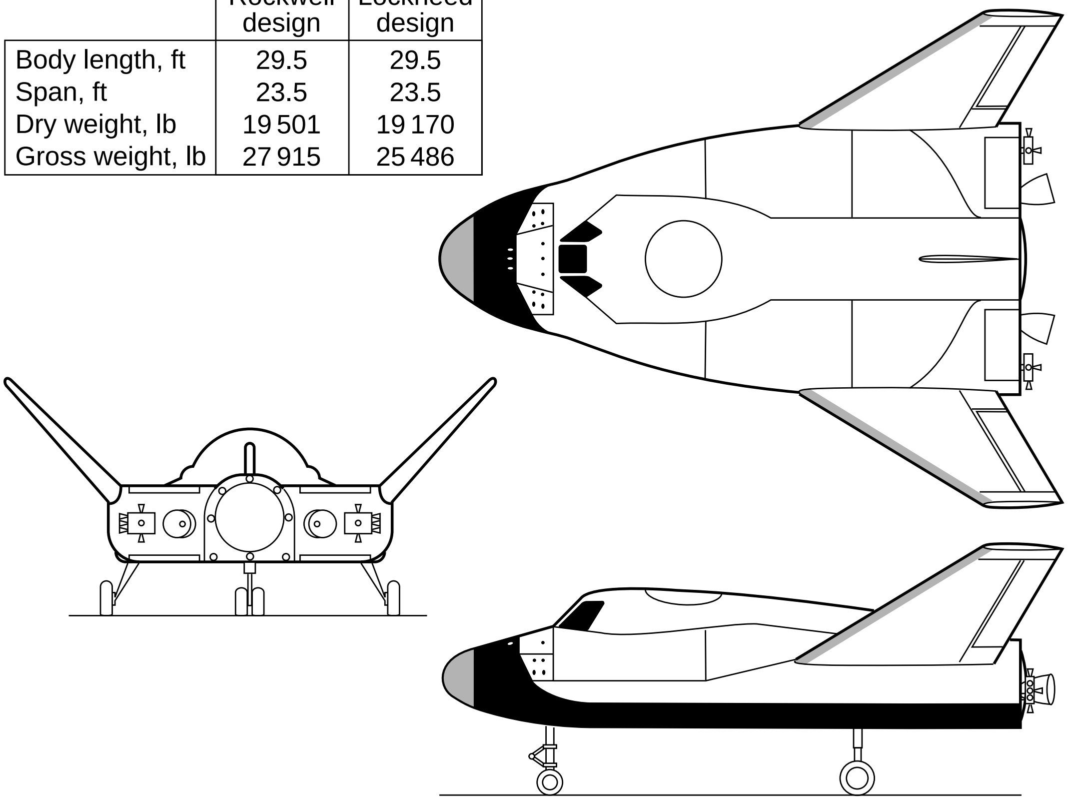

Figure 2. HL-20 lifting body general arrangement.

of 12 would work the second shift and would focus its work on the next flight vehicle.) Ample overtime was available when required. The crew skills mix was typically that of an inspector and one electrical, four mechanical, four avionics, and two propellant/engine technicians. Other skills, such as guidance specialist, could be called upon for preflight operations.

Launch operations usually required two shifts, with the mating operations of the X-15 to the B-52 taking place the day before launch on second shift. Activities for launch would usually begin about 3:00 a.m. on the day of a flight, with fueling and checkout to support a 7:30 a.m. B-52 takeoff and a 9:00 a.m. launch. These activities usually required the full 12-person X-15 support crew plus an additional 4 to 5 propellant/engine specialists, and a 3-person crew for the launch aircraft.

Upon completion of the mission, the same crew that prepared the X-15 for launch usually deserviced and safed the aircraft and removed instrumentation in preparation for return to the hangar. Frequently this could be accomplished before the second-shift operations. For emergency landings of the X-15 at alternate dry lake beds, return to Edwards could take up to 3 days with a flatbed trailer.

During 1965 it required 134 civil service people to operate the fleet of X-15 aircraft (Love and Young 1967). This represented fairly mature operations, with 177 flights completed by the end of this year. The average turnaround for 1965 was 31 calendar days, with some flights having been turned around in as little as 8 days (Love and Young 1967). The 72 maintenance technicians (24 technicians per aircraft for the fleet) working the vehicle maintenance program were supported by the remaining 62 nonmaintenance staff. Although the functions performed by the nonmaintenance staff were not defined by Love, they are believed to have consisted of engineering, quality assurance, process planning, simulation, shop support, training aircraft support, and an administrative staff of unknown size (based on a discussion with Jack Kolf, former X-15 project engineer at Dryden Flight Research Facility). In addition there were 79 people performing mission analysis functions, which included flight planning, mission monitoring and tracking, and data analysis. This annual support manpower of 213 for the X-15 aircraft provides

Table I. X-15 and HL-20 Subsystems for Rockwell and Lockheed Designs

Parameter	X-15	HL-20 Rockwell	HL-20 Lockheed
Body—primary	Titanium and Inconel X structure, Inconel X skin	Aluminum 2219/2024	Aluminum 2219/2024
Body—upper panels	Inconel X skin	Aluminum alloy honeycomb	Aluminum alloy honeycomb
Fins/wings	Titanium and Inconel X structure, Inconel X skin	Graphite polyimide (with TPS)	Titanium honeycomb (with TPS)
Heat shield structure	Inconel X	Graphite polyimide	Titanium isogrid (segmented)
TPS—bottom	Ablative, resin-based glass bead powder (limited use/X-15A-2)	HTP6 (direct bond)	HTP6 (direct bond)
TPS—upper	Ablative, resin-based glass bead powder (limited use/X-15A-2)	AFRSI blanket (direct bond)	AFRSI blanket (direct bond)
TPS—leading edges	Ablative	Advanced carbon carbon	Advanced carbon carbon
Landing gear	Nonsteerable nose wheel (2), main gear skids	All electric fighter gear	All electric fighter gear (F-5 modified)
Main propulsion	Anhydrous ammonia/LOX, helium purge	None	None
RCS propulsion	Hydrogen peroxide, 12 nozzles, 40 to 100 lbf	Hydrogen peroxide	MMH/N_2O_4 (satellite vernier thrusters)
OMS propulsion	None	Hydrogen peroxide/JP-4	MMH/N_2O_4 (STS RCS vernier thrusters)
Prime power	2 APU's driven by hydrogen peroxide for electrical and hydraulics	Rechargeable Ag-Zn batteries	Rechargeable Ag-Zn batteries
Electrical	115 volt ac	dc	dc
Actuators	Hydraulic	Electromechanical/ electrohydraulic	Electromechanical
Avionics	State-of-the-art and advanced systems	State of the art (autonomous/BITE/ HUD/etc.)	State of the art (autonomous/BITE/ HUD/etc.), eliminate microwave landing system
ECLSS	Liquid nitrogen for temperature control of suit, cockpit, and instrumentation	Water loop; solid amine CO_2 removal system	LiOH canisters, ammonia boiler, water loop
Personnel accommodations	Full pressure suit	Apollo-type waste management	Apollo-type waste management
Recovery/abort	Ejection seat	Apollo-type chutes, solid abort motors	Apollo-type chutes/solid abort motors with TVC

a basis for comparison with HL-20 spacecraft support requirements. In addition to the 213 people providing direct support, the X-15 program required 112 people to support the B-52 carrier aircraft, overhaul the XLR99 rocket engine, and provide base support, bringing the total annual manpower requirements to support the X-15 program to 325 people.

HL-20 Turnaround Process

The HL-20 refurbishment process is made up of the safing and deservicing process, the maintenance process, and the integration and launch process. The refurbishment time and manpower are assumed to be driven primarily by the maintenance requirements for the vehicle. In the Rockwell HL-20 study (Ehrlich 1991) the turnaround time and manpower were derived from comparisons with historical aircraft systems maintenance records and adjusted to account for Shuttle support experience on a subsystem by subsystem basis. From this information the number of man-hours required to perform corrective and preventive maintenance was derived

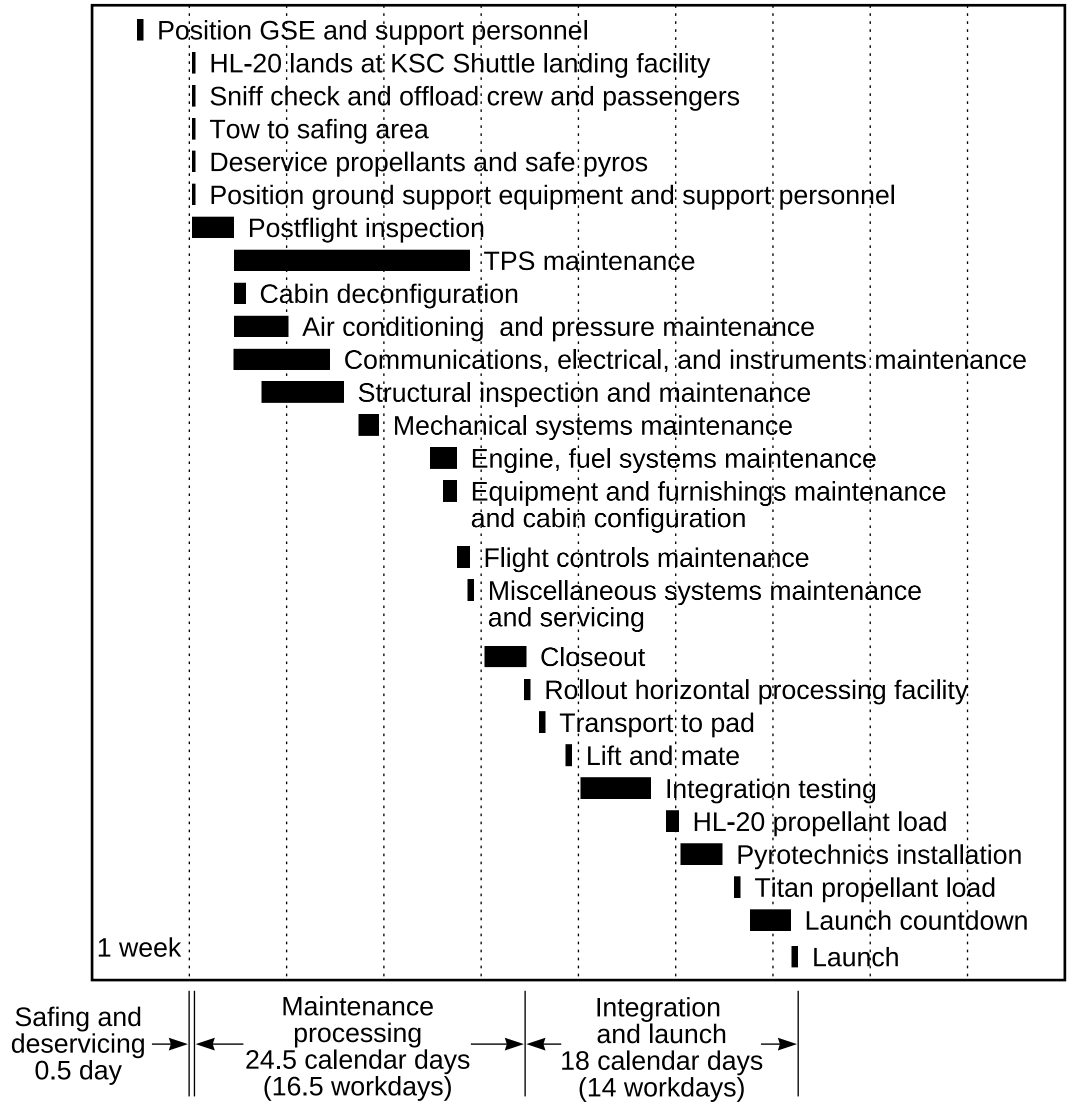

Figure 3. HL-20 processing accomplished in 43 calendar days (31 work days, single-shift operation).

(no vehicle modifications were assumed). As a result, the HL-20 was predicted to require 1486 man-hours of support for the maintenance process. Hands-on support was assumed to be accomplished by highly skilled technicians with A&P (airframe and powerplant) type training as used in the aircraft industry. Although the technicians were highly cross-trained, four skill classifications were assumed: avionics, electrical, mechanical/systems, and thermal protection system (TPS). The tasks to support the vehicle refurbishment processes were determined and scheduled (fig. 3), then man-hour loaded by skill classification. This resulted in a definition of 22 technicians to support the process, including 3 to account for nonproductive time, which includes vacations, holidays, sick leave, etc. These same technicians were assumed available to support the safing and deservicing process and the integration and launch process without additional staffing. The hands-on staff consisted of 3 avionics, 5 electrical, 3 TPS, and 11 mechanical/systems technicians. This staff worked a single-shift, 5-day week throughout the processing. Total man-hour requirements for the turnaround ground operations were 2362, including the 1486 man-hours for the maintenance process, 772 for integration and launch operations, and 104 for the landing, deservicing, and safing operations.

A total of 162 personnel were estimated to support the ground operations. This includes the 22 technicians mentioned above plus the engineering, planning, quality, support, logistics, and administrative departments. The Lockheed "Skunk Works" estimates were somewhat lower for overall personnel, 109, and higher for hands-on labor, 28.

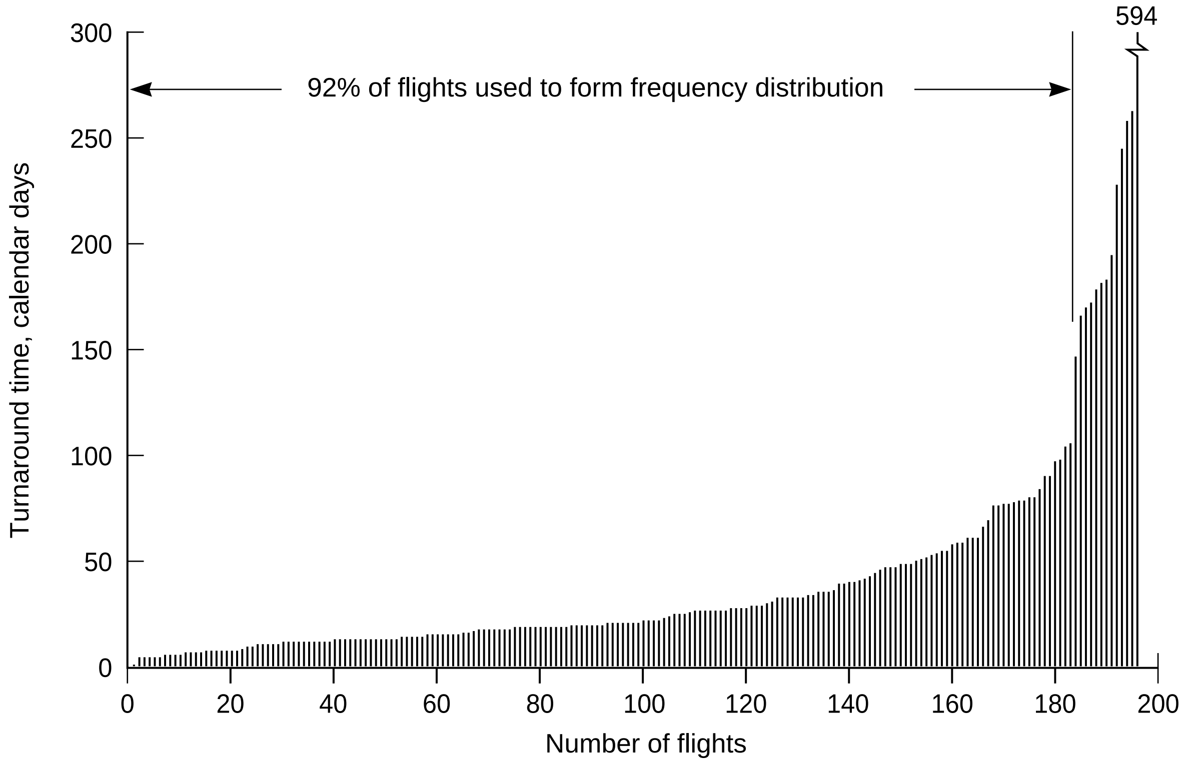

Figure 4. X-15 flights ordered by turnaround time.

The lower ratio of support personnel to hands-on staffing is based on Lockheed's contracted logistics support experience.

In addition to the ground support operations, Rockwell estimated a staff of 205 personnel were required to support mission operations. These flight-specific functions consist of mission planning, simulation, crew activity planning, and real-time support for each flight of the HL-20. Mission support personnel that work generically on all flights and the support staff are not accounted for here. Thus the total supporting staff comparable to the 213 people in the X-15 program would be 367 for the HL-20 during mature operations.

Comparison and Discussion

Ideally one comparison between the support requirements of the X-15 and HL-20 programs should be in terms of the maintenance burden for each vehicle subsystem. The maintenance burden, as used in this report, is the man-hours required for both scheduled and unscheduled maintenance in support of the typical turnaround operation. The maintenance burden is a function of the design, the failure rate, the mission time, and the maintenance policy and can be used to define the average crew size and/or processing time required for the turnaround operation. Unfortunately, this information was not available for the X-15. However, by using the X-15 flight histories, an estimate was derived of the overall X-15 maintenance man-hour burden comparable to an HL-20 man-hour estimate. This was achieved by using the previously presented ground support crew size, as defined by Baker, with the time required for vehicle servicing and maintenance of failures. This maintenance/service time was estimated from the total turnaround time for each flight based on the flight histories in Miller (1983). (See appendix for flight histories of the three aircraft.) The turnaround times were plotted in order of increasing times and are shown in figure 4. These turnaround times include not only scheduled and unscheduled maintenance, but also aircraft modifications, mission aborts, mission delays, and schedule drivers. In an attempt to capture only the required maintenance burden that would be reflected by these turnaround times, the 13 longest were excluded from the analysis along with the turnaround times for the initial flight of each aircraft. These 13 flights were more likely to have included some major modifications and repair or extensive weather and schedule delays. (Based on flights from Sept. 1961 to July 1965, the delays due to weather, aircraft and experiment modifications, and miscellaneous causes represent about 35 percent of the delay times (Love and Young 1966).) There appears to be a clear change in processing times at about the 106-day point. It was felt that the remaining processing times, representing 92 percent of all flights, were more representative of the processing activities, even though these still include some of the more typical delays due to weather, schedule, etc.

From the description given of the X-15 turnaround process, it appears that the equivalent of 1 workday was usually devoted to the integration and mission of the X-15. In an attempt to compare only the maintenance times, a day was subtracted from each of the turnaround times. A frequency distribution was then developed based on 7-day centers and is shown in figure 5. The results indicate that the most frequently experienced maintenance processing time required for the X-15 was about 13 calendar days, or 9 workdays. This should be representative of those maintenance processings that consist primarily of the repair and checkout operations. The longer times shown in figure 5 would be more likely to include vehicle modifications and any delays due to aborts, weather, schedule, etc. This is consistent with results observed during 1964 and 1965, when only one turnaround in three was accomplished without delays or aborts (Love and Young 1967). The maintenance burden can then be computed based on the derived processing time. Thus, the results should be representative of the processing time and maintenance manpower required for the X-15 when minimal modifications or scheduled delays occur during turnaround.

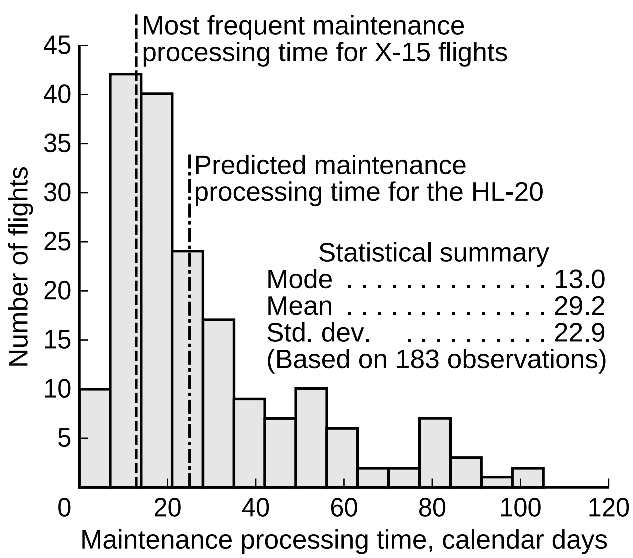

Figure 5. X-15 maintenance processing time histogram.

Using the 24 technicians (2 shifts of 12) over this derived 9-workday period yields 1728 man-hours available to satisfy the maintenance burden for the X-15. Removing 12 percent of the man-hours that typically are required for nonproductive time leaves 1520 productive man-hours. The maintenance burden was then assumed equal to the productive man-hours. By comparison, the maintenance burden for the HL-20, as defined by Rockwell, is 1486 man-hours (Ehrlich 1991). Based on the Rockwell-defined staffing level, 2904 man-hours are available to achieve the total HL-20 refurbishment operations over the 24.5 calendar days typically required (16.5 workdays) during the turnaround process. The Lockheed-defined burden for the maintenance is 1718 man-hours (the specific time period for maintenance operations was not defined). These findings are summarized in table II.

Although the maintenance processing time estimated for the HL-20 is greater than that experienced by the X-15 and the man-hours required to satisfy the maintenance burden less, these results probably lie within the uncertainty band associated with the assumptions made in the derivation of these results. The longer mission length for the HL-20 could be expected to generate higher maintenance requirements than if it flew the shorter duration X-15 mission. The additional time available for the HL-20 processing provides a margin of 1486 additional man-hours that can be applied should the actual maintenance requirements exceed the predicted burden. Based on the assumption of design comparability, the HL-20 support estimate would appear to be comparable to that experienced by the X-15.

The integration and launch operations were excluded from this comparison. With the X-15 requiring only 1 day for this process and the HL-20 requiring 14 workdays, clearly the integration and launch process is driven by different requirements for these two systems. For example, the HL-20 requires a launch escape system that must be integrated with the launch vehicle, whereas the X-15 did not.

Another method of comparison between the two programs is based on the total available man-hours to support the total turnaround process (safing, deservicing, maintenance, integration, and launch). This involves using the typical X-15 processing times that were achieved. Shorter turnaround times could have been achieved (and frequently were), but the schedule may not have required it. These comparisons are a function of the flight rate.

During 1965 and 1966, the X-15 fleet was flown at a rate of over 30 flights per year (no flights from Nov. 4, 1965 to May 6, 1966) representing an average turnaround time of 36.5 calendar days (26 workdays)

Table II. Operations Support Requirements for X-15 and HL-20

Parameter	X-15	HL-20 Rockwell	HL-20 Lockheed
Length, ft	50	29.5	29.5
Span, ft	22	23.5	23.5
Dry weight, lb	15 000	19 501	19 170
Gross weight, lb	33 300	27 915	25 486
Flight crew and passengers	1	10	8
Technology level	Advanced	Near term	Near term
Mission types	Research	Operational	Operational
Hands-on crew per turnaround	24	22	28
Skills	Electrical (1) Mechanical (3) Avionics (4) Propellant/engine (2) Crew chief (1) Inspector (1)	Electrical (5) Mechanical/systems (11) Avionics (3) TPS (3)	Avionics (9) Systems (11) NDE (3) Inspector (5)
Maintenance hands-on man-hours per maintenance processing (burden/available)	1520/1728 (based on productive man-hours/total man-hours, 13 workdays)	1486/2904 (based on comparable aircraft systems/16.5 workdays)	1718/N/A (based on comparable Shuttle systems/not defined)
Hands-on man-hours available per turnaround (safe, maintain, integrate, and launch)	4992 (includes mission, based on 26 workdays)	5456 (excludes mission, based on 31 workdays)	6720 (excludes mission, based on 30 workdays)
Flight rate per year	10 (based on 1 aircraft)	8	8
Fleet size	3	3	3
Support staff (includes hands-on)	134 (supports 30 flights/yr)	162	109
Mission operations and analysis support	79	205 (excludes all-flight and nonflight support staff)	Not addressed
Launch vehicle support	Excluded	Excluded	Excluded

for each aircraft (or a flight rate of 10 flights per year for each aircraft). This represents 4992 man-hours available from the hands-on support crew for each mission.

By comparison, the Rockwell analysis predicts the HL-20 will require a hands-on staff of 22 technicians, working 1 shift, 5-day weeks, 43 calendar days (31 workdays) to receive, safe, refurbish, integrate, and prepare it for launch. This represents 5456 man-hours per mission. This analysis was based on 8 flights per year. For the same flight rate, the Lockheed analysis resulted in 6720 man-hours based on using 28 technicians over 42 calendar days to support the turnaround process. (This information was presented at the HL-20 PLS Feasibility Assessment Contractor Review, Dec. 10–11, 1991.) Their crew makeup and size were dictated by skill requirements and vary slightly from the hands-on crew requirements of the Rockwell study. For example, Lockheed considers the NDE (nondestructive evaluation) technicians and inspectors to be a part of the hands-on crew, whereas Rockwell considered these as support functions. The X-15 program also used NDE personnel but in a support role. Because of the low flight rate, the support man-hours are spread over a longer period than the maintenance burden would require to process the HL-20.

The similarities in subsystems, support staffs, and overall processing times would imply a certain degree of comparability between the support required for the two vehicles. But, there are also a number of differences that need to be noted. Technologies used by the X-15 represented cutting-edge technologies at that time. They included Inconel skin, titanium structure, reaction control systems (RCS), highly sophisticated throttleable rocket power, integrated control systems, and flight simulators using analog technology. In addition these technologies were flown in altitude and speed regimes not previously explored. It might reasonably be expected that the failure rates and repair times experienced with these systems would be higher than in an operational program where the technologies were more state of the art. Technologies chosen for the HL-20 represent existing and near-term technologies (ceramic tiles, ACC, blanket TPS, titanium or aluminum structure, hydrogen peroxide RCS, GN&C, etc.). The maintenance concept for the X-15 represented a support environment for an experimental program that involved development, modifications, and flying experimental systems, which also had to be maintained. The HL-20 is to have a repeatable, specific mission to perform, for which there should be no modifications or experimental packages to complicate the maintenance function. Therefore, a more operational maintenance environment should be applicable.

Charles Baker and Jack Kolf of the X-15 program have added some additional cautions to these comparisons. Charles Baker indicated that a two-shift operation may be required for the HL-20 instead of the one shift proposed. This could create two shifts whose total manpower requirements would be slightly larger than those required for single-shift operations in order to meet minimum skill requirements on each shift. Jack Kolf indicates that the use of a thermal protection system in the HL-20 that is robust and easily penetrated for access to the subsystems may represent the difference between being able to perform aircraft-like maintenance on the HL-20 or requiring the much longer process times associated with the Space Shuttle.

It is interesting to note that based on the first 7 years of the X-15 flight experience, Love and Young believed that the turnaround time for a similar type of vehicle without the research role and associated instrumentation might be as low as 15 days (Love and Young 1967). This estimate would apply to a prototype or an initial production model of a reusable vehicle.

An additional consideration is the support environment in which the HL-20 will operate. It will most likely be different from that of the X-15 in the 1950's and 1960's. The types of safety and environmental rules that exist today were essentially nonexistent at that time. For example, more stringent requirements are placed on the handling and disposal of hazardous materials today. Along with this comes new operating procedures and additional training requirements. Work procedural changes mean additional oversight in safety and quality assurance. These would certainly add to the support requirements if the X-15 program were repeated today.

Concluding Remarks

The X-15 program successfully demonstrated the ability to support a reusable vehicle operating in a near-space environment with a flight rate and support staff similar to that predicted for the HL-20. Given an operating environment similar to that experienced by the X-15, subsystem comparability, and a similar support environment, the HL-20 maintenance and support crew complement should be able to achieve the turnaround time predicted for the HL-20. The HL-20 will, however, be operating in a different environment than existed at Edwards AFB during the 1950's and 1960's. Today's operating environment will likely impose additional requirements on the HL-20 that will add to the maintenance and support burden predicted by using the X-15 analogy.

NASA Langley Research Center
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April 22, 1993

Appendix A

X-15 Turnaround Times

Table A1. X-15 Turnaround Times (Miller 1983)

All aircraft: (199 flights)				No. 1 aircraft: (81 flights)			No. 2 aircraft: (53 flights)			No. 3 aircraft: (65 flights)		
Flight no.	Date	Aircraft no.	Days	Flight no.	Date	Days	Flight no.	Date	Days	Flight no.	Date	Days
1	6/8/59	1		1	6/8/59		2	9/17/59		46	12/20/61	
2	9/17/59	2	101	5	1/23/60	229	3	10/17/59	30	48	1/17/62	28
3	10/17/59	2	30	9	3/25/60	62	4	11/5/59	19	49	4/5/62	78
4	11/5/59	2	19	12	4/13/60	19	6	2/11/60	98	51	4/20/62	15
5	1/23/60	1	79	13	4/19/60	6	7	2/17/60	6	57	6/12/62	53
6	2/11/60	2	19	14	5/6/60	17	8	3/17/60	29	58	6/21/62	9
7	2/17/60	2	6	15	5/12/60	6	10	3/29/60	12	62	7/17/62	26
8	3/17/60	2	29	16	5/19/60	7	11	3/31/60	2	65	8/2/62	16
9	3/25/60	1	8	18	8/4/60	77	17	5/26/60	56	67	8/14/62	12
10	3/29/60	2	4	19	8/12/60	8	26	11/15/60	173	71	10/4/62	51
11	3/31/60	2	2	20	8/19/60	7	28	11/22/60	7	73	10/23/62	19
12	4/13/60	1	13	21	9/10/60	22	30	12/6/60	14	75	12/14/62	52
13	4/19/60	1	6	22	9/23/60	13	34	3/7/61	91	76	12/20/62	6
14	5/6/60	1	17	23	10/20/60	27	35	3/30/61	23	77	1/17/63	28
15	5/12/60	1	6	24	10/28/60	8	36	4/21/61	22	79	4/18/63	91
16	5/19/60	1	7	25	11/4/60	7	37	5/25/61	34	81	5/2/63	14
17	5/26/60	2	7	27	11/17/60	13	38	6/23/61	29	82	5/14/63	12
18	8/4/60	1	70	29	11/30/60	13	40	9/12/61	81	84	5/29/63	15
19	8/12/60	1	8	31	12/9/60	9	41	9/28/61	16	85	6/18/63	20
20	8/19/60	1	7	32	2/1/61	54	43	10/11/61	13	87	6/27/63	9
21	9/10/60	1	22	33	2/7/61	6	45	11/9/61	29	90	7/19/63	22
22	9/23/60	1	13	39	8/10/61	184	53	5/8/62	180	91	8/22/63	34
23	10/20/60	1	27	42	10/4/61	55	55	6/1/62	24	94	11/7/63	77
24	10/28/60	1	8	44	10/17/61	13	60	6/29/62	28	96	11/27/63	20
25	11/4/60	1	7	47	1/10/62	85	63	7/19/62	20	99	1/16/64	50
26	11/15/60	2	11	50	4/19/62	99	66	8/8/62	20	101	2/19/64	34
27	11/17/60	1	2	52	4/30/62	11	68	8/20/62	12	102	3/13/64	23
28	11/22/60	2	5	54	5/22/62	22	69	8/29/62	9	106	5/12/64	60
29	*11/30/60	1	8	56	6/7/62	16	70	9/28/62	30	108	5/21/64	9
30	12/6/60	2	6	59	6/27/62	20	72	10/9/62	11	111	7/8/64	48
31	12/9/60	1	3	61	7/16/62	19	74	11/9/62	31	112	7/29/64	21
32	2/1/61	1	54	64	7/26/62	10	109	6/25/64	594	113	8/12/64	14
33	2/7/61	1	6	78	4/11/63	259	114	8/14/64	50	115	8/26/64	14
34	3/7/61	2	28	80	4/25/63	14	118	9/29/64	46	116	9/3/64	8
35	3/30/61	2	23	83	5/15/63	20	121	11/30/64	62	117	9/28/64	25
36	4/21/61	2	22	86	6/25/63	41	127	2/17/65	79	120	10/30/64	32
37	5/25/61	2	34	88	7/9/63	14	131	4/28/65	70	122	12/9/64	40
38	6/23/61	2	29	89	7/18/63	9	132	5/18/65	20	124	12/22/64	13
39	8/10/61	1	48	92	10/7/63	81	137	6/22/65	35	125	1/13/65	22
40	9/12/61	2	33	93	10/29/63	22	139	7/8/65	16	126	2/2/65	20
41	9/28/61	2	16	95	11/14/63	16	141	8/3/65	26	130	4/23/65	80
42	10/4/61	1	6	97	12/5/63	21	146	9/2/65	30	134	5/28/65	35

*Values corrected based on Hallion 1984.

Table A1. Continued

All aircraft: (199 flights)				No. 1 aircraft: (81 flights)			No. 2 aircraft: (53 flights)			No. 3 aircraft: (65 flights)		
Flight no.	Date	Aircraft no.	Days	Flight no.	Date	Days	Flight no.	Date	Days	Flight no.	Date	Days
43	10/11/61	2	7	98	1/8/64	34	155	11/3/65	62	135	6/16/65	19
44	10/17/61	1	6	100	1/28/64	20	158	5/18/66	196	138	6/29/65	13
45	11/9/61	2	23	103	3/27/64	59	159	7/1/66	44	140	7/20/65	21
46	12/20/61	3	41	104	4/8/64	12	162	7/21/66	20	143	8/10/65	21
47	1/10/62	1	21	105	4/29/64	21	164	8/3/66	13	145	8/26/65	16
48	1/17/62	3	7	107	5/19/64	20	167	8/12/66	9	148	9/14/65	19
49	4/5/62	3	78	110	6/30/64	42	170	8/30/66	18	150	9/28/65	14
50	4/19/62	1	14	119	10/15/64	107	175	11/18/66	80	152	10/12/65	14
51	4/20/62	3	1	123	12/10/64	56	180	5/8/67	171	154	10/27/65	15
52	4/30/62	1	10	128	2/26/65	78	186	8/21/67	105	161	7/18/66	264
53	5/8/62	2	8	129	3/26/65	28	188	10/3/67	43	165	8/4/66	17
54	5/22/62	1	14	133	5/25/65	60				168	8/19/66	15
55	6/1/62	2	10	136	6/17/65	23				172	9/14/66	26
56	6/7/62	1	6	142	8/6/65	50				174	11/1/66	48
57	6/12/62	3	5	144	8/25/65	19				176	11/29/66	28
58	6/21/62	3	9	147	9/9/65	15				178	4/26/67	148
59	6/27/62	1	6	149	9/22/65	13				181	5/17/67	21
60	6/29/62	2	2	151	9/30/65	8				183	6/22/67	36
61	7/16/62	1	17	153	10/14/65	14				185	7/20/67	28
62	7/17/62	3	1	156	11/4/65	21				187	8/25/67	36
63	7/19/62	2	2	157	5/6/66	183				189	10/4/67	40
64	7/26/62	1	7	160	7/12/66	67				190	10/17/67	13
65	8/2/62	3	7	163	7/28/66	16				191	11/15/67	29
66	8/8/62	2	6	166	8/11/66	14						
67	8/14/62	3	6	169	8/25/66	14						
68	8/20/62	2	6	171	9/8/66	14						
69	8/29/62	2	9	173	10/6/66	28						
70	9/28/62	2	30	177	3/22/67	167						
71	10/4/62	3	6	179	4/28/67	37						
72	10/9/62	2	5	182	6/15/67	48						
73	10/23/62	3	14	184	6/29/67	14						
74	11/9/62	2	17	192	3/1/68	246						
75	12/14/62	3	35	193	4/4/68	34						
76	12/20/62	3	6	194	4/26/68	22						
77	1/17/63	3	28	195	6/12/68	47						
78	4/11/63	1	84	196	7/16/68	34						
79	4/18/63	3	7	197	8/21/68	36						
80	4/25/63	1	7	198	9/13/68	23						
81	5/2/63	3	7	199	10/24/68	41						
82	5/14/63	3	12									
83	5/15/63	1	1									
84	5/29/63	3	14									
85	6/18/63	3	20									
86	6/25/63	1	7									
87	6/27/63	3	2									
88	7/9/63	1	12									

Table A1. Continued

All aircraft: (199 flights)				No. 1 aircraft: (81 flights)			No. 2 aircraft: (53 flights)			No. 3 aircraft: (65 flights)		
Flight no.	Date	Aircraft no.	Days	Flight no.	Date	Days	Flight no.	Date	Days	Flight no.	Date	Days
89	7/18/63	1	9									
90	7/19/63	3	1									
91	8/22/63	3	34									
92	10/7/63	1	46									
93	10/29/63	1	22									
94	11/7/63	33	9									
95	11/14/63	1	7									
96	11/27/63	3	13									
97	12/5/63	1	8									
98	1/8/64	1	34									
99	1/16/64	3	8									
100	1/28/64	1	12									
101	2/19/64	3	22									
102	3/13/64	3	23									
103	3/27/64	1	14									
104	4/8/64	1	12									
105	4/29/64	1	21									
106	5/12/64	3	13									
107	5/19/64	1	7									
108	*5/21/64	3	2									
109	6/25/64	2	35									
110	6/30/64	1	5									
111	7/8/64	3	8									
112	7/29/64	3	21									
113	8/12/64	3	14									
114	8/14/64	2	2									
115	8/26/64	3	12									
116	9/3/64	3	8									
117	9/28/64	3	25									
118	9/29/64	2	1									
119	10/15/64	1	16									
120	10/30/64	3	15									
121	11/30/64	2	31									
122	12/9/64	3	9									
123	12/10/64	1	1									
124	12/22/64	3	12									
125	1/13/65	3	22									
126	2/2/65	3	20									
127	2/17/65	2	15									
128	2/26/65	1	9									
129	3/26/65	1	28									
130	4/23/65	3	28									
131	4/28/65	2	5									
132	5/18/65	2	20									
133	5/25/65	1	7									

*Values corrected based on Hallion 1984.

Table A1. Continued

All aircraft: (199 flights)				No. 1 aircraft: (81 flights)			No. 2 aircraft: (53 flights)			No. 3 aircraft: (65 flights)		
Flight no.	Date	Aircraft no.	Days	Flight no.	Date	Days	Flight no.	Date	Days	Flight no.	Date	Days
134	5/28/65	3	3									
135	6/16/65	3	19									
136	6/17/65	1	1									
137	6/22/65	2	5									
138	6/29/65	3	7									
139	7/8/65	2	9									
140	7/20/65	3	12									
141	8/3/65	2	14									
142	8/6/65	1	3									
143	8/10/65	3	4									
144	8/25/65	1	15									
145	8/26/65	3	1									
146	9/2/65	2	7									
147	9/9/65	1	7									
148	9/14/65	3	5									
149	9/22/65	1	8									
150	9/28/65	3	6									
151	9/30/65	1	2									
152	10/12/65	3	12									
153	10/14/65	1	2									
154	10/27/65	3	13									
155	11/3/65	2	7									
156	11/4/65	1	1									
157	5/6/66	1	183									
158	5/18/66	2	12									
159	7/1/66	2	44									
160	7/12/66	1	11									
161	7/18/66	3	6									
162	7/21/66	2	3									
163	7/28/66	1	7									
164	8/3/66	2	6									
165	8/4/66	3	1									
166	8/11/66	1	7									
167	8/12/66	2	1									
168	8/19/66	3	7									
169	8/25/66	1	6									
170	8/30/66	2	5									
171	9/8/66	1	9									
172	9/14/66	3	6									
173	10/6/66	1	22									
174	11/1/66	3	26									
175	11/18/66	2	17									
176	11/29/66	3	11									
177	3/22/67	1	113									
178	4/26/67	3	35									
179	4/28/67	1	2									

Table A1. Concluded

All aircraft: (199 flights)				No. 1 aircraft: (81 flights)			No. 2 aircraft: (53 flights)			No. 3 aircraft: (65 flights)		
Flight no.	Date	Aircraft no.	Days	Flight no.	Date	Days	Flight no.	Date	Days	Flight no.	Date	Days
180	5/8/67	2	10									
181	5/17/67	3	9									
182	6/15/67	1	29									
183	6/22/67	3	7									
184	6/29/67	1	7									
185	7/20/67	3	21									
186	8/21/67	2	32									
187	8/25/67	3	4									
188	10/3/67	2	39									
189	10/4/67	3	1									
190	10/17/67	3	13									
191	11/15/67	3	29									
192	3/1/68	1	107									
193	4/4/68	1	34									
194	4/26/68	1	22									
195	6/12/68	1	47									
196	7/16/68	1	34									
197	8/21/68	1	36									
198	9/13/68	1	23									
199	10/24/68	1	41									

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1993	Technical Memorandum

4. TITLE AND SUBTITLE
X-15/HL-20 Operations Support Comparison

5. FUNDING NUMBERS
WU 906-11-01-01

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Hampton, VA 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER
L-17190

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-4453

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited

Subject Category 15

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
During the 1960's, the United States X-15 rocket-plane research program successfully demonstrated the ability to support a reusable vehicle operating in a near-space environment. The similarity of the proposed HL-20 lifting body concept in general size, weight, and subsystem composition to that of the X-15 provided an opportunity for a comparison of the predicted support manpower and turnaround times with those experienced in the X-15 program. Information was drawn from both reports and discussions with X-15 program personnel to develop comparative operations and support data. Based on the assumption of comparability between the two systems, the predicted staffing levels, skill mix, and refurbishment times of an operational HL-20 appear to be similar to those experienced by the X-15 for ground support. However, safety, environmental, and support requirements have changed such that the HL-20 will face a different operating environment than existed at Edwards during the 1950's and 1960's. Today's operational standards may impose additional requirements on the HL-20 that will add to the maintenance and support burden estimate based on the X-15 analogy.

14. SUBJECT TERMS
X-15; HL-20; Operations; Support

15. NUMBER OF PAGES
16

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500

Standard Form 298(Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102