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SURVEY OF OPERATION AND COST EXPERIENCE OF THE X-15 AIRPLANE AS A REUSABLE SPACE VEHICLE

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SUMMARY

The X-15 airplane has been flown more than 150 times in an environment similar to that anticipated for many of the reusable space vehicles being studied. Data are presented on X-15 development and operational costs, turnaround time, and refurbishment cycles, based upon actual operation of the aircraft. For example, 27 flights were accomplished in 1964 at a total cost of $16,268,000, or an average cost of more than $602,000 per flight.

It is believed that information from the X-15 program will be helpful in feasibility studies of the reusable-vehicle concept, inasmuch as the X-15 operation is more directly comparable than any other operational program to the reusable systems being considered.

INTRODUCTION

Since the beginning of this nation's space program, the number of launches per year of personnel and equipment has increased from 5 in 1958 to more than 70 in 1964 and 65 in 1965 (ref. 1). The increase in total program cost with launch frequency has focused attention upon finding a more economical means of launching and recovering space vehicles. A reusable vehicle, such as a first-stage booster and/or an orbital transport, is one method being investigated as a means of reducing the cost per flight. The consideration of reusable boost and flight vehicles is enhanced by the foreseeably large number of flights for such purposes as resupply of life-support equipment and consumable supplies and rotation of personnel to orbiting space stations, in addition to global transportation of passengers and cargo. The launching of lunar and interplanetary exploratory missions, as contrasted with the launch and resupply of orbital space stations, would involve a lower launch frequency but still would be of sufficient quantity for the utilization of reusable vehicles to be considered.

Actual development and operational cost figures for reusable space vehicles have not been available. The theoretical cost figures being generated must, of necessity, be estimates or extrapolations of information from operations of existing heavy bomber or jet-transport aircraft. It is difficult, therefore, to accurately compare actual disposable-booster costs and theoretical reusable-booster costs. The X-15 airplane, however, is an operating, reusable space vehicle. The program provided over 5 years of actual flight experience from which data on operations and costs can be obtained.

This paper presents this information which can provide a basis for studies of initial production or prototype, reusable space vehicles.

The units used for the physical quantities in this paper are given both in the U. S. Customary Units and in the International System of Units (SI).

THE X-15 PROGRAM

The X-15 airplane was first flown in June 1959; since then, more than 150 flights have been completed in the three X-15 vehicles. Two of the vehicles have each been recovered and reused more than 50 times. The third vehicle has been flown for more than 40 flights. The performance envelope extends to an altitude of 67 miles (108,000 meters) and a velocity of greater than 6000 feet per second (1830 meters per second). In addition a dynamic pressure of 2000 pounds per square foot (95,800 newtons per square meter) and surface temperatures greater than 1300° F (705° C) have been experienced.

A modified B-52 airplane serves as the launch platform for the X-15 aircraft and provides an initial velocity of approximately 600 feet per second (183 meters per second) at 45,000 feet (13,700 meters) altitude. The YLR99 liquid-fuel rocket engine, which burns 9 tons (8160 kilograms) of propellants in approximately 1.5 minutes, powers the X-15 to its programed altitude and velocity. During the remaining glide portion of the flight (approximately 9.5 minutes), the pilot executes a reentry and maeuvers for a landing. Additional details of X-15 operations and research efforts and results are included in references 2 to 5.

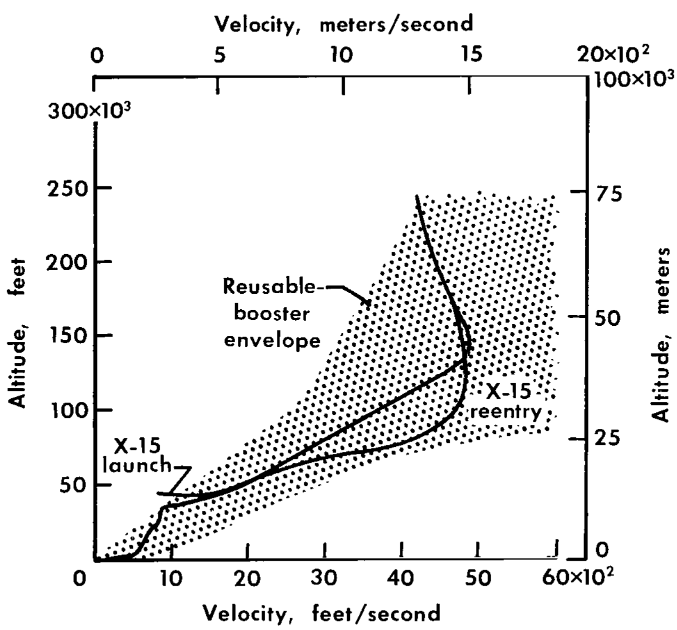

Figure 1.– Comparison of a typical X-15 profile with reusable-booster envelope.

Figure 1 shows a typical X-15 flight profile to an altitude of 250,000 feet (76,200 meters) superimposed upon the altitude—velocity envelope in which reusable boosters and space vehicles will probably operate. The accelerations, dynamic pressures, and heating rates resulting from this X-15 environment are similar to those that would be experienced by a reusable booster vehicle. Various characteristics of the X-15 and a generalized reusable booster (refs. 6 and 7) are compared in table I. The major differences are in weight, wing loading, and payload. The weight of the X-15 is about one-fiftieth that of the reusable booster, the wing loading is about one-half that of the booster, and the payload is proportionately one-fifth that of the booster. The payload difference would be less, considering that about one-third of the booster payload consists of upper stages. The other parameters are similar to those of a generalized reusable booster.

TABLE I. – COMPARISON OF X-15 AIRPLANE AND A GENERALIZED REUSABLE BOOSTER

	X-15 airplane	Generalized reusable booster
Weight, launch, pounds (kilograms)	33,000 (14,900)	1,560,000 (708,000)
Payload-to-weight ratio, launch	0.06	0.33
Thrust-to-weight ratio, launch	1.7	1.5
Launch or lift-off velocity, feet/second (meters/second)	600 (183)	650 (198)
Wing loading, pounds/foot^2 (newtons/meter^2)	165 (7900)	325 (15,560)
Staging or maximum velocity, feet/second (meters/second)	6000 (1830)	6100 (1858)
Staging or normal maximum altitude, feet (meters)	250,000 (76,200)	250,000 (76,200)
Landing speed, knots (meters/second)	200 (103)	190 (98)
Type of propellant	Chemical cryogenic	Chemical cryogenic

OPERATIONAL EXPERIENCE

The X-15 has achieved its research objectives through the accomplishment of successful flights. Program effectiveness measured against any other factor tells only part of the story. The number of successful flights depends upon the turnaround cycle, which is defined as the time from when the air vehicle returns from a flight until it completes its next successful flight. Refurbishment time, which is included in the turnaround cycle, is the time from when the air vehicle returns from a flight until it is ready for another flight.

Figure 2 shows the average turnaround time of all X-15 flights through 1965. A smoothing process was used for the data presented; five consecutive flights were averaged to obtain a point, for example, flights 80 to 85, then 81 to 86, and so on. In 1962, 180 days required for X-15-1 modification were omitted, and in 1962-63, 482 days of X-15-2 modifications were omitted. The plot has an annual peak and seasonal cycle. Each flight requires good visibility and clear weather along the 250 miles of the flight path, which, of course, contributes to longer turnaround times during the winter. The circles, which indicate yearly averages, show that the turnaround time has varied from 20 to 40 days. Although in the last 4 years, the turnaround cycle has not changed significantly from 30 days per flight, it is felt that the time could have been reduced if a formal product-improvement program had been initiated. It is believed that turnaround for a similar type of vehicle, without a research program and associated instrumentation, could be accomplished in about 20 days, which is in sharp contrast to an estimated reusable-booster turnaround time of 3 to 7 days (refs. 6 to 8). It is believed that this difference (20 days compared with 3 to 7 days) is a result of using actual experience to obtain a more realistic estimate.

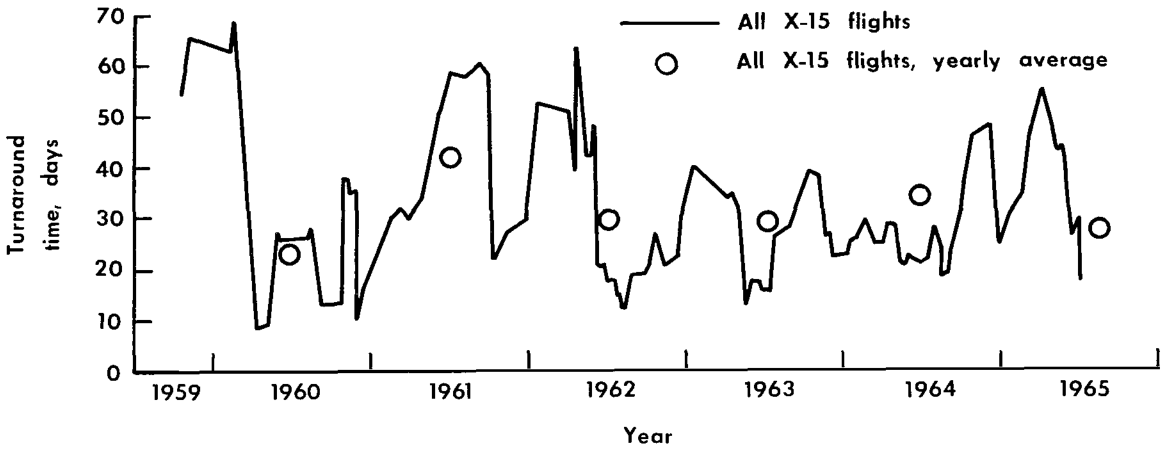

Figure 2.— Average turnaround time per aircraft (based upon average of five successive flight groups).

Figure 3 shows a breakdown of the time involved in turnaround of the three X-15 airplanes from September 1961 to July 1965. Only the predominant cause of turnaround delay was tabulated for each day; minor items which occurred simultaneously were not accounted for. Routine maintenance and preflight preparation absorbed almost 38 percent of the total time, followed by weather at greater than 12 percent. Airframe problems were third, at almost 11 percent; landing-gear malfunctions and canopy-glass failures early in the program contributed heavily to this category. No deterioration of the basic structure has been evident. There has been buckling and

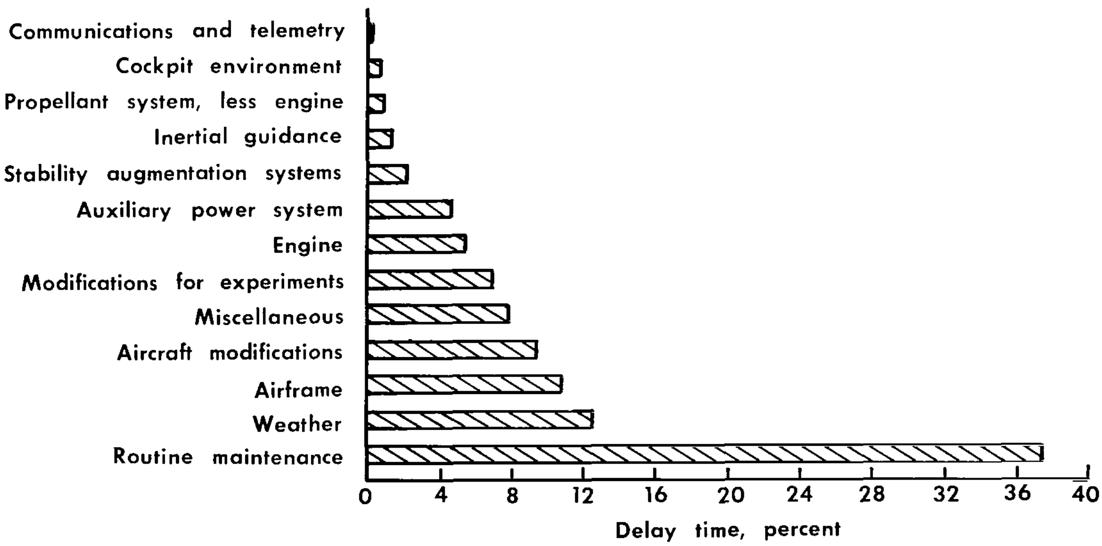

Figure 3.— Distribution of turnaround time in percent. September 1961 to July 3, 1965.

deformation of some of the nonload-carrying members, but the integrity of the structure has not been compromised. In fact, inspection during the turnaround cycle has made it possible to detect progressive failures before they become serious. Aircraft modifications, which were fourth, consisted primarily of routine design improvements and accident repair. The "miscellaneous" category includes the more than 150 days from the date of the X-15-2 accident in November 1962 until the contract was signed to rebuild and modify the aircraft for research flights to a Mach number of 8, including the use of the aircraft as the test-bed for supersonic-combustion ramjet flight tests. The "engine" category includes engine changes as well as corrective engine maintenance without removal. As shown in figure 4, engine changes per flight from 1961 to 1965 have varied from 0.85 to 0.37. From 1961 to mid-1965, there was an average of two flights per engine change. Additional information concerning the engine and the problems of the remaining subsystems listed in figure 3 is available in reference 9.

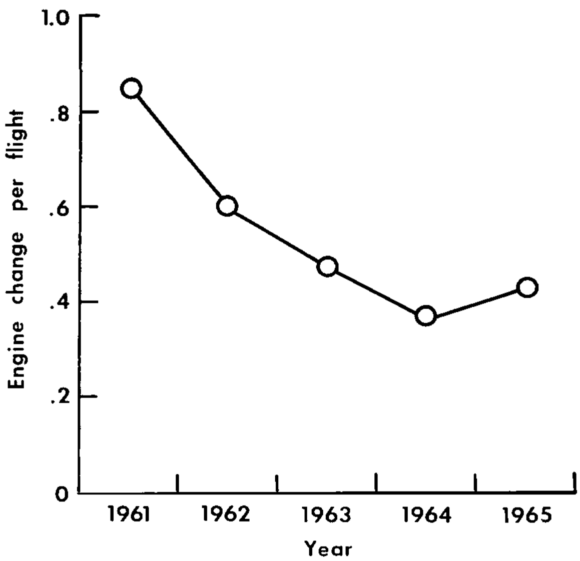

Figure 4.– Engine changes per flight, by years.

PROGRAM COSTS

The total initial program cost was $162.80 million in terms of 1957-1959 buying power. Table II shows the initial costs of developing and building three X-15 airplanes and their associated equipment. As indicated, the cost of the airframe development, manufacture, and flight test represented 45 percent of the total. The YLR99 rocket engine costs amounted to one-third of the total. The rocket engine and the systems listed were supplied independently of the airframe.

Table III shows the unit cost per pound (kilogram) of selected systems. Unit cost per pound (kilogram) is a rule-of-thumb that may be used for estimation purposes. Components with similar type construction or function are likely to have a similar cost. For example, the stability augmentation system and the inertial flight data system, which are similar types of electronic systems, have similar unit cost per pound (kilogram). Also, the unit cost per pound (kilogram)--$6670--of the inertial flight data system developed in 1963 for the X-20 Dyna-Soar compares favorably with the cost shown for the X-15 systems. The initial costs of the items listed include development cost for the X-15 as well as development and modification cost for the B-52 airplane. The order-of-magnitude difference between the costs of the X-15 airframe and the entire B-52 most likely results from the difference in the design mission and state-of-the-art technology during development.

TABLE II. – INITIAL X-15 PROGRAM COSTS

	Cost, millions of dollars		Percentage of total
Airframe –			
Development and flight tests	49.90		
3 airframes	23.51		
Subtotal		73.41	45
Engine –			
Development	43.79		
10 rocket engines	10.04		
Subtotal		53.83	33
Aircraft systems –			
Auxiliary power units	2.70		
Inertial flight data systems	3.40		
Adaptive control systems	2.30		
Flow-direction sensor (ball nose)	.60		
Pressure suits	.15		
Subtotal		9.15	6
Aerospace ground equipment (AGE) and peripheral equipment –			
Launch platform (modify two B-52 airplanes)	3.26		
Airframe AGE and spares	6.70		
Engine AGE and spares	4.06		
Systems spares	.10		
Propulsion system test stand	.41		
Monitoring station construction	5.81		
Mission control	6.07		
Subtotal		26.41	16
Total		162.80	100

TABLE III. – UNIT COSTS PER POUND (KILOGRAM) OF SELECTED X-15 SYSTEMS

[Initial procurement]

	Total cost, millions of dollars	Number of units	Unit empty weight, pounds (kilograms)	Cost per pound (kilogram), dollars
X-15 airframe	73.41	3	12,650 (5,740)	1,930 (4,260)
Engine	53.83	10	915 (415)	5,900 (12,970)
Stability augmentation system	1.40	4	65 (29)	5,400 (12,069)
Inertial flight data system	3.40	6	120 (54)	4,700 (10,500)
Auxiliary power unit	2.70	16	45 (20)	3,750 (8,438)
Flow-direction sensor	.60	6	78 (35)	1,300 (2,857)
B-52 airplane	62.02	2	177,500 (80,500)	170 (385)

Table IV is a breakdown of X-15 manpower and cost requirements for each of the supporting agencies for one year of operation. The year 1964 was chosen as typical of annual manpower requirements and costs. The total effort in manpower and dollars has remained much the same from year to year. Normally, initial manpower requirements and costs should decrease as the experience level increases. However, in the X-15 program, each year additional instrumentation, new experiments, modification, and repair requirements have offset any reduction in costs, even though manpower requirements have been reduced by one-third since the start of the program (1959). There has been no significant change in total cost per year, although the number of flights has varied from 20 to 40 (fig. 2). Costs would decrease substantially if the X-15 project were not a research program. Items such as research and data reduction, instrumentation and data processing, escort aircraft and logistics, and the space-positioning operation would not necessarily apply to a reusable system. As noted, the total of $16.268 million does not include the cost of military manpower. The 27 successful flights for the year (1964) cost slightly more than $602,000 each. Note that operating cost per year is approximately 10 percent of the initial cost.

TABLE IV. – TYPICAL ANNUAL MANPOWER REQUIREMENT AND X-15 OPERATING COST

[1964]

	Manpower, man-years		Cost, millions of dollars	
	Military	Civilian	Manpower[1]	Material
NASA Flight Research Center –				
Operate and maintain three X-15 airplanes	----	146.0	1.825	0.800
Flight planning	----	10.0	.200	-----
Research and data processing	----	92.0	1.874	.300
Space-positioning operations	----	35.0	.438	-----
Contractor support:				
Shop fabrication	----	-----	.011	-----
Computer and instrument maintenance	----	15.0	.133	.020
Space-positioning operations	----	33.0	.550	-----
Space-positioning modifications and spares	----	-----	-----	.200
Air Force Flight Test Center –				
B-52 support	11.4	3.9	.025	.281
Escort aircraft and logistics	12.2	4.4	.029	.255
General-purpose maintenance support	.3	2.4	.030	.054
Propellant handling	3.0	15.0	.115	.075
Rocket engine and auxiliary power unit overhaul	9.0	29.0	.242	.050
Bioastronautics	8.0	-----	.010	.090
Instrumentation and data processing	1.5	12.0	.084	.144
Base engineering, fire protection, etc.	10.0	11.0	.039	.072
USAF Aeronautical Systems Division –				
Management support:	5.0	5.0	.060	-----
Propellants	----	-----	-----	.700
2 new pressure suits	----	-----	-----	.020
6 radios	----	-----	-----	.165
Contractor support:				
Airframe –				
Engineering support	----	60.0	2.482	-----
Logistics	----	13.0	-----	-----
Parts repair or replacement	----	-----	-----	1.287
Spare parts	----	-----	-----	1.334
Rocket engine –				
Engineering support and analyst	----	-----	.200	-----
Parts repair and 2 technical representatives	----	-----	-----	.800
Spare parts	----	-----	-----	.400
Inertial flight data systems –				
Logistics and service representatives	----	-----	.220	-----
Modify X-20 inertial system	----	-----	-----	.654
Subtotal	60.4	486.7	8.567	7.701
Total	547.1		16.268	

[1]Military manpower costs are not available. Civilian costs include overhead and burden.

Refurbishment cost, as used herein, is that portion of operating cost required to return the X-15 airplane to flight status after a flight. It includes all shop support, spare parts, engineering, and miscellaneous support, as shown in table V. Here, again, costs for the typical year, 1964, are used. The vehicle's ground-crew effort is not included in refurbishment cost, even though the crew performs many of the tasks required to return the vehicle to flight status. As shown, the total refurbishment costs for 1964 were $7.288 million, or slightly less than one-half of the total operations cost. The average cost per flight for the 27 successful flights was $270,000.

TABLE V. – TYPICAL X-15 REFURBISHMENT COSTS

[1964]

	Cost, millions of dollars
Shop support, 7 men at $10,000 per year, NASA	0.070
Shop fabrication, contractor	.011
YLR99 engine and auxiliary power unit overhaul and maintenance, USAF	.292
Instrumentation maintenance, contractor	.040
Airframe spares	1.334
Airframe parts repair or replacement, contractor	1.287
Engine spares	.400
Engineering support, 4 men at $13,000 per year, NASA	.052
Airframe engineering support, contractor	2.482
Engine engineering support, contractor	1.000
Inertial flight data system support	.220
Miscellaneous	.100
Total	7.288
Average cost for 27 flights - $270,000	

The cost of a complete, new X-15 vehicle, as obtained recently from the contractor, is shown in table VI. If the X-15 aircraft were not reusable, the 27 successful flights for the year considered would have cost $243 million. The ratio of refurbishment cost ($270,000) for reuse of the X-15 to the cost of using a new X-15 ($9 million) for each flight was 0.03 per flight or 3 percent.

TABLE VI. – COST OF A NEW X-15 AIRPLANE

	Cost, millions of dollars
Airframe and basic subsystems	7.50
Engine	1.00
Flow-direction sensor	.08
Inertial system	.15
Miscellaneous	.27
Total	9.00

It is obvious that the research program would have been drastically curtailed if the X-15 aircraft had not been reusable.

CONCLUDING REMARKS

The X-15 program has provided more than 5 years of actual flight experience from which data on operations and costs for a reusable space vehicle can be obtained. The information applicable to reusable space vehicles has been presented in this paper, but no attempt has been made to determine how the information should be applied to future studies.

In 1964, 27 X-15 flights were accomplished at a total cost of $16,268,000. The average cost per flight has been more than $602,000, and the average turnaround time has been 30 days per mission. Both of these factors are greater than estimates for a reusable booster, because of the research nature of the X-15 program and because the X-15 airplane is equivalent to a prototype vehicle. An estimated 33-percent reduction in turnaround time and a proportionate cost reduction would result from the elimination of the X-15 research requirement. An additional reduction in turnaround time would have resulted if a product-improvement phase had been undertaken. Even so, the present estimates and extrapolations for future reusable boosters and orbital space vehicles appear to be overly optimistic in comparison to the actual X-15 experience, especially in the length of time required for turnaround.

The refurbishment cost of the X-15, which has been 3 percent of the cost of a new X-15 for each flight, demonstrates an advantage of reuse.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., August 10, 1966.
719-04-00-06-24

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