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Saturn V Derivatives

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THE NASA, IN ASSOCIATION WITH INDUSTRY, has developed a launch vehicle system that surpasses the capability and utility of any known system in the world today. Success of Saturn flights has demonstrated vehicle dependability and established a high level of confidence. Evidence to support the statement is reflected in Figure 2, "The Successful Launch of SA-501!"

A vast industrial complex geared to the fabrication, assembly, transportation, and launch of the Saturn V has been assembled. It is of utmost importance that any derivative launch vehicle concept maximize the utilization of these facilities and management capabilities.

For the meaningful exploitation and exploration of space to continue at a reasonable pace, it is imperative that launch vehicle concepts offer maximum returns in capability and utility at minimum total program cost. Therefore, it is desirable to determine the suitability of existing vehicles and stages to accomplish projected missions when compared with potential new launch systems, and to conserve our nearer-term development funds for expanding the market for these systems.

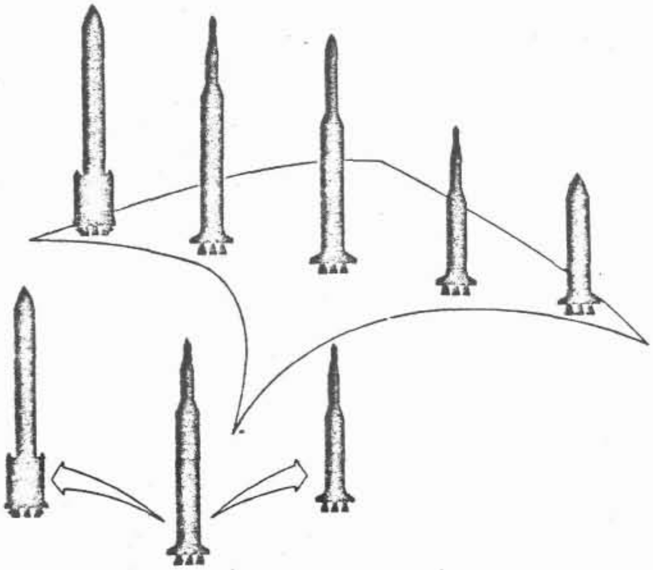

Fig. 1 - Saturn V derivatives

This paper presents four essential items: (1) the capability of the standard operational Saturn V; (2) several derivative launch vehicle concepts resulting from the many in-house and contracted improvement studies; (3) identification of a near-term, low R&D cost, intermediate derivative launch vehicle; (4) development of a hypothesized evolutionary Saturn V family concept that spans the earth

ABSTRACT

This paper describes an evolutionary family concept of Saturn V derivative launch vehicle systems, discusses their performance capabilities, and outlines their ability to perform orbital and high-energy missions at minimum total program cost. The versatility and utility of the Saturn V launch vehicle system have been well publicized with respect to its ability to inject sizeable exploratory payloads throughout the Solar System and with respect to its earth orbital capability to exploit near earth by utilizing a manned space station derived from the third stage. The complete flexibility of the evolutionary Saturn V system is identified through derivative launch vehicle concept which utilize a "common core" design. These vehicles demonstrate potential ability to span the earth orbital and planetary payload spectrum. The validity of this evolutionary concept is analyzed and derivative candidates are evaluated in terms of design commonality and traffic levels. Resources and schedule information is provided for an evolutionary development plan that could satisfy civilian space exploitation requirements for the foreseeable future. The theme is maximum utilization of present equipment, facilities, Saturn V hardware items and engineering techniques to ensure compatibility of present and future designs.

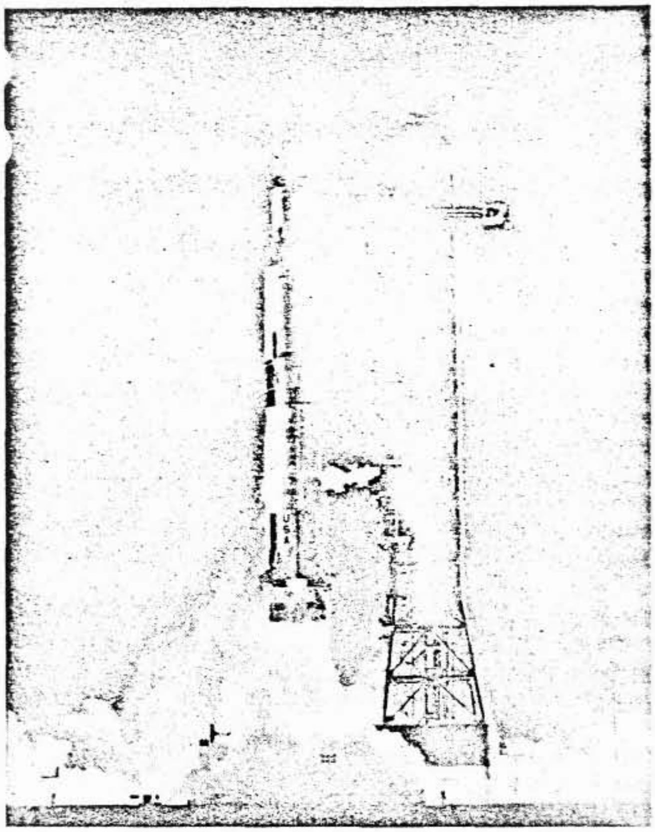

Fig. 2 - AS-501 launch

orbital payload spectrum from 50,000 pounds to over 500,000 pounds.

The paper describes the Saturn V and its evolutionary family of two- and three-stage derivative launch vehicles, discusses their performance capabilities, and outlines their ability to perform, cost effectively, orbital missions programs and potential high-energy missions. These derivative configurations have a payload capability range extending from that of the Saturn IB to the postulated manned planetary vehicle requirements which might include placing larger nuclear modules/stages in rendezvous compatible orbits about the earth.

Basic information on launch vehicle configurations, i.e., technical descriptions, performance data, and resources data, was extracted from recent NASA-funded study documentation. Mission and cost data were prepared at MSFC.

Many alternative methods of providing launch capability for the complete payload spectrum have been conceived, evaluated and aggressively compared with respect to design, schedules, and resources. As a result, the authors contend that the present national inventory of launch vehicles does not provide any overwhelming direction for the utilization of present systems to satisfy future requirements. However, when one compares competitive launch vehicle systems in a single or select range (e.g., intermediate payload range of 110,000 pounds in LEO) the danger exists for comparison out of context with respect to resources and/or launch rates or, perhaps, a comparison of existing or early modified configurations with merely publicized future concepts.

To arrive at a true program cost comparison for derivative vehicles, the cost of introducing and producing each new vehicle over and above that for the basic Saturn V must be determined. A three- or four-per-year production rate is below the design production rate for Saturn V facilities. When derivative vehicles using Saturn V elements are produced in addition to Saturn V, their program costs are minimized because Saturn V facilities are then used more effectively. For comparisons of Saturn derivatives, either uprated or derated configurations, the candidate should be selected with respect to a vehicle evolutionary concept where an assumed three-stage Saturn V baseline production program exists and the complete mission spectrum requirements are evaluated with respect to this open-ended development concept. In this paper the validity of this evolutionary concept is analyzed and Saturn V derivative candidates are evaluated in terms of performance, design commonality, cost and traffic levels.

The philosophy expressed throughout this paper is the considered opinion of the authors and does not necessarily reflect MSFC or NASA management approved direction for any future program.

THE SATURN V

The focal point or key to the evolutionary common core concept, which will be developed within this paper, is the "Standard Saturn V." Designed for the Apollo missions, the Saturn V has the capability of injecting sizeable exploratory payloads throughout the solar system by housing the payload within a shroud of selected length to remain within the design capabilities of the current vehicle.

The upper right half of Figure 3 shows the Saturn V with a variable payload height depicted by the dashed line and the net injected payload capability as a function of the energy parameter C_3 is shown in the lower right. The mission profile assumes three-stage ascent to a 100 n. mi. parking orbit with restart of the S-IVB stage to inject the payload to a range of energy levels. The Saturn V high-energy injection capability does not approach zero until a C_3 of approximately 150 km^2/sec^2 (Ref. 2).* For reference, local escape is $C_3 = 0$, and a Mars transfer is approximately $C_3 = 18\ km^2/sec^2$.

The curve labeled "J-2S" refers to the performance obtainable by incorporating an improved propulsion system in the second and third stages. The J-2S is a simplified

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*Numbers in parentheses designated References at end of paper.

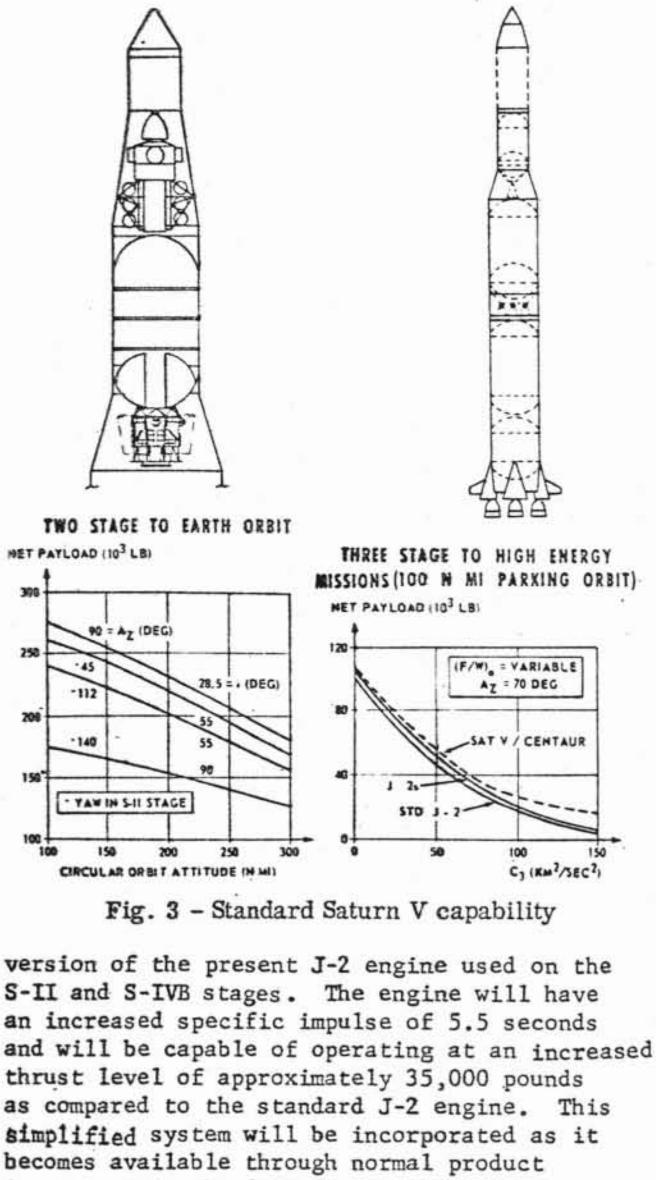

Fig. 3 - Standard Saturn V capability

version of the present J-2 engine used on the S-II and S-IVB stages. The engine will have an increased specific impulse of 5.5 seconds and will be capable of operating at an increased thrust level of approximately 35,000 pounds as compared to the standard J-2 engine. This simplified system will be incorporated as it becomes available through normal product improvement. The dashed curve depicts the performance increase achieved when the Centaur is used as an additional propulsive stage on the Saturn V. For example, the stage might be integrated within the existing LEM adapter section (SLA) of the standard Saturn V/Apollo vehicle. This configuration is shown in the upper right corner of Figure 10.

The Saturn V has a tremendous potential for earth orbital applications. By utilizing the first two stages to achieve orbit, the third stage "derivative" becomes a ground-fitted, prelaunch-checked-out, manned space station. This concept retains the external configuration of the standard Saturn V/Apollo vehicle. Once earth orbit has been achieved, the possibility exists to derive from the second stage a hangar, additional storage area, counter weight for "g" simulation or other possible applications. The earth orbit performance capability of the Saturn V and an artist's concept of a derivative manned space station are displayed in the left half of Figure 3.

The earth orbital payload capability is shown as a function of circular earth orbit altitude. The family of curves results by varying launch azimuth and the initiation of yaw steering to achieve various inclinations of the final orbit. Selection of the azimuth and time to initiate the yaw maneuver was based on range safety limitations; the inclinations were chosen according to possible experimentor requirements.

The basic Saturn V and the "orbital core derivatives" are presented only to emphasize the versatility and utility of the Saturn V as an evolutionary base. This now permits us to undertake the primary discussion of the paper, i.e., Saturn V derivatives as an evolutionary launch vehicle system concept.

- POST APOLLO TIME FRAME
- EMPHASIS ON MISSION FLEXIBILITY
- MAXIMUM UTILIZATION OF EXISTING CAPABILITIES AND RESOURCES
- DERIVATIVE CONCEPTS DO NOT REPRESENT APPROVED PROGRAMS

Fig. 4 - Guidelines

GUIDELINES FOR DERIVATIVE CONCEPTS

The specific guidelines shown in Figure 4 were used to identify configurations peculiar to the stated philosophy and rationale.

Not only is the Saturn V the means to send American Astronauts to the moon, it is also a versatile machine to lift gigantic space stations into earth orbit or to launch instrument laden spacecraft to the planets; however, we must appreciate the necessity for no advanced program interfering with the timely execution of the nationally committed Apollo project. Therefore, a non-interference policy sets the initial guideline of an assumed post-Apollo time frame for initiating a Saturn derivative program to encompass the foreseeable payload spectrum.

All vehicles must meet Apollo design specifications and reliability standards, thereby encompassing the spectrum of manned and unmanned flights to give the greatest potential mission flexibility.

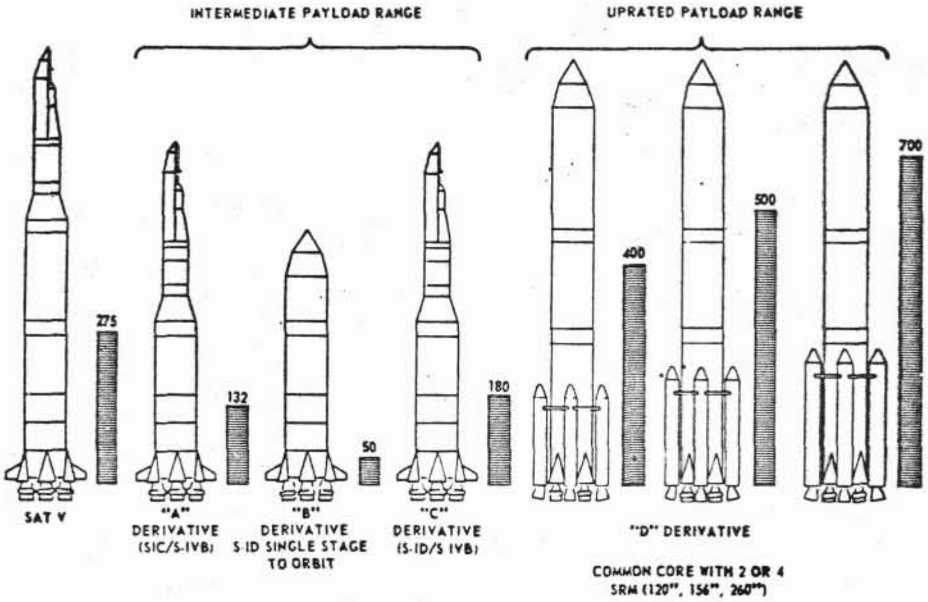

Fig. 5 - Saturn V derivative, payload flexibility and hardware utility

With the vast technological abilities developed, it is only fitting to assume that for derivative concepts all hardware items and engineering techniques developed under present programs will be utilizied to the maximum extent permissible. This philosophy extends to all technical and management areas, including design, fabrication, assembly, transportation, launch, and utilization of ailable manpower and funding resources. Therefore, one of the most important guidelines to the maximum use of available equipment and ow-how, thereby insuring exploitation of the Apollo investment.

Because the Saturn V derivative concepts, encompassing both uprated and derated candidate vehicles, are under consideration for planning purposes only, they do not represent or require approved hardware programs. This allows a variety of concepts to be considered and evaluated as possible candidates for the next generation of Saturn launch vehicles.

SATURN V DERIVATIVE FAMILY

Two of the major problems facing space program planners are (1) the payload gap between Saturn IB and Saturn V low earth orbit capabilities, and (2) the probable requirement for a capability beyond that of Saturn V for the more ambitious manned planetary programs of the future. Cost analyses have indicated that only a single, modest R&D expenditure is required to implement the configurations necessary to encompass this payload spectrum with a Saturn V evolutionary vehicle family. is suggests that the program planner would en have the flexibility of selecting the vehicle that matches each of the numerous yloads which could materialize in this nge ... in a most cost-effective manner. This being the case, the concept of a Saturn V derivative fleet of vehicles is evolved to serve as a possible solution to the space program planners' predicament.

The Saturn V derivative concepts that demonstrate the payload flexibility and hardware utility of proven systems are presented in Figure 5. These launch vehicles can successfully support both planetary missions and earth orbital missions for the payload ranges indicated. These future configurations are arranged chronologically with respect to availability dates and could essentially be divided into the following categories: (1) The near-term "A" derivative comprised of Saturn first and third stages; and (2) the far-term derivatives --- "B", "C" and "D" --- comprised of a lengthened and strengthened Saturn V common core with or without solid propellant rocket motor strap-ons and accompanying core derivatives as indicated. The economic common core concept is dependent upon a requirement for uprating the present Saturn capabilities; whereas, the nearer term "A" derivative is independently available by combining existing systems without large R&D expenditures.

When the decision is made to uprate the present Saturn V family, one derivative that should be given careful consideration is the S-ID single stage to orbit. This derivative, designated "B", is a stage and one-half version of the present S-IC stage and would become the first stage in an effective and economical assembly of upper stages of the evolutionary Saturn family. These two- and three-stage vehicles would form an impressive family of vehicles that range from the S-ID with its staged thrust structure to the three-stage (S-ID/S-II/S-IVB) vehicle with solid rocket motors for auxiliary booster thrust.

Only low earth orbit (LEO) payload capabilities are portrayed by the payload bars adjacent to the derivative vehicles for the 100-n. mi. circular orbit. Synchronous equatorial orbit (SEO) and earth gravitational escape capabilities will be discussed in detail with the major characteristics of each derivative. Incremental payload flexibility is achieved by varying the number of stage engines or SRM strap-ons.

The economical gains achieved by simultaneously developing the entire fleet of vehicles are significant. The combined development of the vehicle family not only provides payload flexibility and more reliable vehicles, but also reduces the development cost by almost 40 percent from that required to develop such vehicles separately. This large economy results from reduced DDT&E costs and fewer R&D flights because of vehicle element commonality. The design commonality and impact aspects of common core fleet development will be presented later in Figure 13.

"A" DERIVATIVE (S-IC/S-IVB)

The most direct approach to providing a low-cost, low-risk, near-term intermediate payload launch capability is to combine the first and third stages of the Saturn V. The resulting S-IC/S-IVB vehicle is shown in Figure 6.

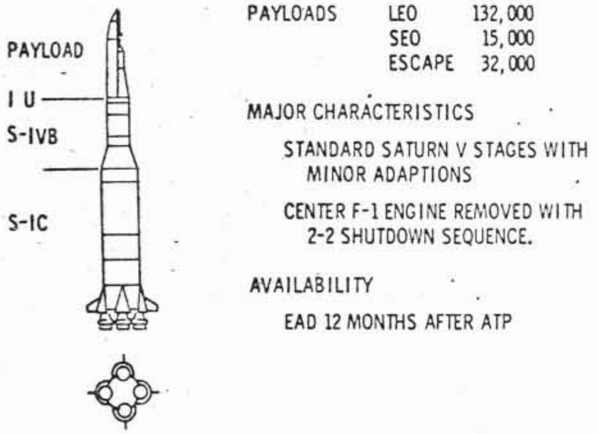

Fig. 6 - "A" derivative (S-IC/S-IVB)

This "A" derivative vehicle can be built by adapting existing equipment and is particularly versatile because it can be tailored for a range of payload capabilities. This tailoring is accomplished by installing only those F-1 engines that are required to meet mission demands and by varying the first stage propellant loading to match launch thrust-to-weight requirements. Four feasible vehicles are thus obtained. The 100-n. mi. orbit payload range available for the four F-1 engine configuration indicates a maximum LEO capability of 132,000 pounds when operating within the present 4.68-g design acceleration limit of the Saturn V. With minor changes in the S-IC and S-IVB propellant tank aft bulkheads an increase in the acceleration limit to 6.0 g can be achieved, resulting in larger payload values up to 158,000 pounds in LEO. SEO and escape capabilities of 15,000 and 32,000 pounds, respectively, are shown

The nominal payload capabilities obtained using various engine combinations for a 100-n. mi. circular earth orbit mission launched due east from KSC are shown in the following table:

No. of F-1 on S-IC	Acceleration Limit 4.68 g	6.0 g
2	36,000 lb	60,000 lb
3	78,000 lb	103,000 lb
4	132,000 lb	138,000 lb
5	133,000 lb	158,000 lb

The existing Saturn V stages can be easily adapted to the S-IC/S-IVB configuration. The S-IC stage is adapted by removing (or not installing) one or more of the F-1 engines and associated components. Installation of a modification kit will complete the adaptation. The modification kit is comprised of cover plates, seals, plugs, caps, heat shield panels, support, and electrical and plumbing adapters. Cover plates and seals close the LOX and fuel bulkheads where lines are removed. Heat shield panels are installed where engines have been removed. It should be noted that the S-IC stage adaptations are reversible; that is, a Saturn V configuration can be obtained by reversing the modification procedure.

The changes to the S-IVB stage are even simpler. A cabling adapter is needed between the S-IC cable interface and the S-IVB cable interface; and the number, size, and location of bolt holes in the aft interface frame must be changed to correspond with the S-IC forward interface frame bolt hole pattern.

The Instrument Unit will require minor internal changes for all intermediate vehicle applications. These changes include reprogramming the launch vehicle digital computer and changing the gains in the flight control computer.

For the "A" Derivative illustrated in Figure 6, the center F-1 engine is removed from the S-IC stage to remain within existing design tolerances and a 2-2 engine shutdown sequence is programmed. Two F-1 engines will therefore experience a 61-second extended operation over present Saturn V burntime. Extended burntime is not a problem, but would require demonstration.

The earliest availability date (EAD) for delivery of the initial operational unit is 12 months after the authority to proceed (ATP) date, which follows a complete program definition phase.

"B" DERIVATIVE (S-ID)*

A stage-and-one-half to orbit version of the S-IC, shown in Figures 7 and 8 and designated S-ID, is worthy of consideration

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*The S-ID single stage to orbit concept resulted from a Boeing Company in-house study.

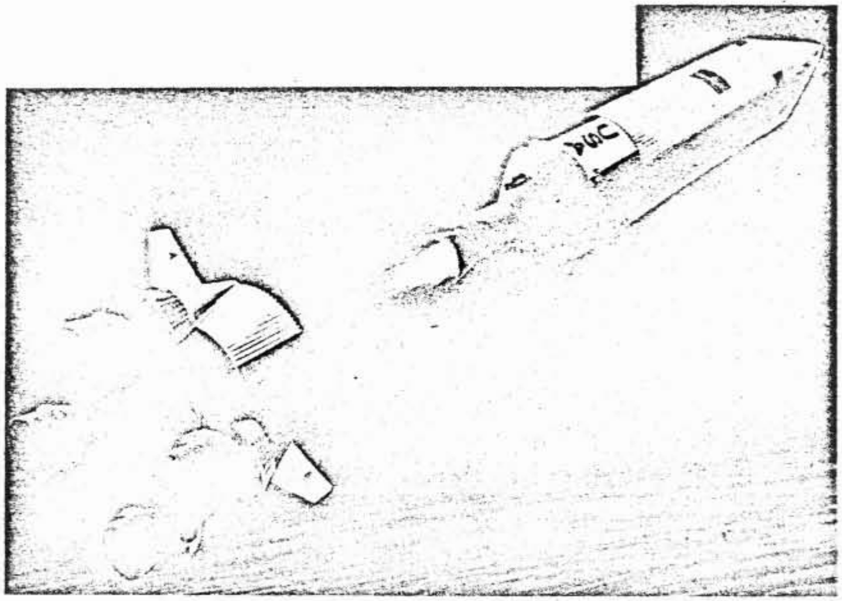
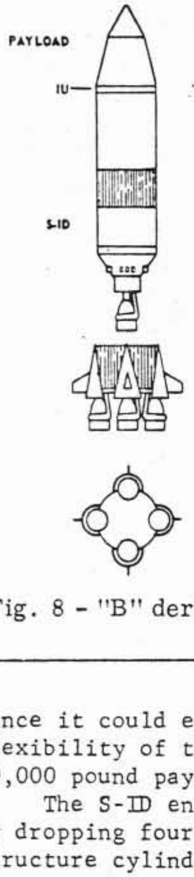


Fig. 7 - S-ID single stage to orbit



- PAYLOAD LEO 50,000
- MAJOR CHARACTERISTICS
  - S-IC STAGE WITH JETTISONABLE THRUST STRUCTURE
  - GIMBAL CENTER SUSTAINER ENGINE WITH EXTENDED BURN TIME
  - OUTBOARD ENGINES AND STRUCTURE STAGED AT 70% PROPELLANT DEPLETION.
- AVAILABILITY
  - EAD 36 MONTHS AFTER ATP

Fig. 8 - "B" derivative (S-ID single stage to orbit)

since it could efficiently round out the flexibility of the Saturn V system in the 50,000 pound payload range.

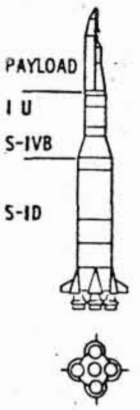
The S-ID engine staging concept operates by dropping four engines and the thrust structure cylinder. The present S-IC thrust structure center engine support cross beam is eliminated for the S-ID concept except for a small cruciform near the inboard engine. A cylinder is used to adapt the remaining cross beam to a conical support which transfers center engine loads to the stage cylindrical wall. This effectively separates the inboard engine from the four outboard engines and their supporting structure. At approximately percent of propellant depletion the four outboard engines are shut down and their respective prevalves close, sealing the lox and fuel ducts from the engines. On separation command, the thrust structure is separated at the forward thrust ring permitting the four-engine pod to fall away from the mainstage and its single F-1 sustainer engine.

LEO payload of 50,000 pounds is obtained with a standard S-IC stage length of 138 feet; however, it should be noted that an increase in stage length, dependent upon the propellant capacity required for the selected uprating step, will significantly increase this capability. For example, a 20-foot extension results in total lift-off weight of 6.01 million pounds, including the S-IC propellant weight of 5.60 million pounds. With a thrust-to-weight ratio at lift-off of 1.266, this vehicle can place in LEO a payload weighing 65,000 pounds.

The center F-1 engine that is used to achieve orbit, after the four outboard F-1 engines and thrust structure are staged, must have an extended operational duration of 192 seconds, over that of Saturn V, for the standard length S-IC and 217 seconds for the 20-foot-extended-length S-IC. Extended burntime is not considered to be a problem, but would require demonstration.

The earliest availability date for this configuration is 36 months after ATP. This schedule is paced by design, manufacture, and test of the necessary test stages and components.

Brief studies indicate that recovery of the thrust structure and engines is feasible. The four outboard engines and thrust structure, when separated, represent a package of high-cost items. Moreover, since the payload-to-inert-weight ratio of the one-half stage is on the order of 1 to 10 (1 lb payload loss to 10 lb inert weight added), necessary recovery equipment may be added with minimum payload degradation. However, for purposes of this paper, no consideration is given to the economics of recovery concepts.



PAYLOADS LEO 180,000
SEO 28,000
ESCAPE 45,000

MAJOR CHARACTERISTICS

STANDARD S-IVB UPPER STAGE

S-IC STAGE WITH JETTISONABLE THRUST STRUCTURE. CENTER F-1 SUSTAINER ENGINE.

AVAILABILITY

EAD 36 MONTHS AFTER ATP

Fig. 9 - "C" derivative (S-ID/S-IVB)

"C" DERIVATIVE (S-ID/S-IVB)

An additional degree of flexibility accrues to the Saturn V derivative vehicle system in the intermediate payload range when the S-IC stage is replaced by the S-ID stage on the "A" derivative (S-IC/S-IVB) launch vehicle, as indicated in Figure 9. The payload increase and flexibility of such an arrangement was demonstrated in Figure 5.

The concept must be used on configurations with either three or five F-1 engines, since the center engine is required as a sustainer after staging the outboard engines and thrust tructure. Note that the 180,000-pound capability of the five F-1 engine vehicle is approaching the 275,000-pound range of the two-stage Saturn V. The SEO of 28,000 pounds achieved without the use of a third stage, e.g., Centaur, is significant. This derivative also injects 46,000 pounds to a lunar transfer trajectory.

The major characteristics of this derivative vehicle are the utilization of the standard S-IVB upper stage of the Saturn V with minor adaptations and the S-IC stage with the jettisonable thrust structure. The center F-1 engine is once again used as the sustainer engine after staging and is required to burn approximately 190 seconds longer than the present Saturn V engines.

The earliest availability date for an operational "C" derivative, paced by the S-ID stage development, is 36 months after ATP.

"A" AND "C" PERFORMANCE COMPARISON

It is interesting to compare the high-energy performance capabilities of derivatives "A" and "C". Figure 10 shows the increased high-energy mission payload capability of a five F-1 engine "C" derivative (S-ID/S-IVB) compared with the four F-1 engine "A" derivative (S-IC/S-IVB). The difference between these vehicles is the ability of the " vehicle to stage the thrust structure with the four outboard engines. As a point of reference, the equivalent energy level required for several representative missions is indicated at the top of the figure.

The mission profile used in achieving the high-energy missions assumes direct ascent to a 100-n. mi. circular parking orbit with restart of the S-IVB stage to inject the payload to the various energy levels (C_3).

The dashed lines indicate the additional performance expected with a Centaur stage integrated into configurations as an additional propulsive stage. A concept showing how the Centaur might be integrated within the Saturn LEM Adapter (SLA) portion is displayed in the configuration "blow up" to the right of the performance plots.

The "A" derivative effectively fills the intermediate payload regime (20,000 lb) for the lower-energy missions to Mars and Venus. A Centaur version, designated "A"/Centaur on the graph (Figure 10), can extend the payload injection capability to the more demanding energy levels ($C_3 = 150\ \mathrm{km}^2/\mathrm{sec}^2$) and become competitive with the Saturn V. The "C" derivative increases the Mars/Venus type payload capability, as compared with "A", by approximately 50 percent.

In order to fully appreciate the capabilities of the derivative vehicles, the Saturn V and Saturn V/Centaur performance has been included on the chart. Depending upon the requirements, i.e., larger payloads, shorter trip times, etc., the Saturn V derivatives and Saturn V/Centaur can encompass the total payload and energy spectrum.

"D" DERIVATIVE - THE UPRATING STEP

The ultimate in Saturn V evolutionary concepts, with respect to flexibility and capability, is achieved when some future requirement dictates development of the "D" derivative shown in Figure 11. This vehicle falls into a category identified by the authors as the uprating step. It will come about when more ambitious missions are undertaken or when existing programs desire sizeable expansion. Therefore, the forcing functions will be a requirement for a ground-fitted lunar base, manned planetary missions, nuclear module flights and/or other forecasted requirements.

The uprating step should be viewed in terms of using evolutionary systems development with emphasis on incorporating the following design goals into the "D" derivative design:

1. Maximum payload envelope -- The core stages should be designed to a 33-foot-diameter payload, with maximum vehicle height attainable under reasonable launch facility constraints.

2. A common core should be introduced to encompass the previously discussed derivatives "B" and "C". The versatility of 0, 2, and 4 SRM strap-ons should be incorporated to provide payload/cost flexibility. The effect of the S-ID application must be considered

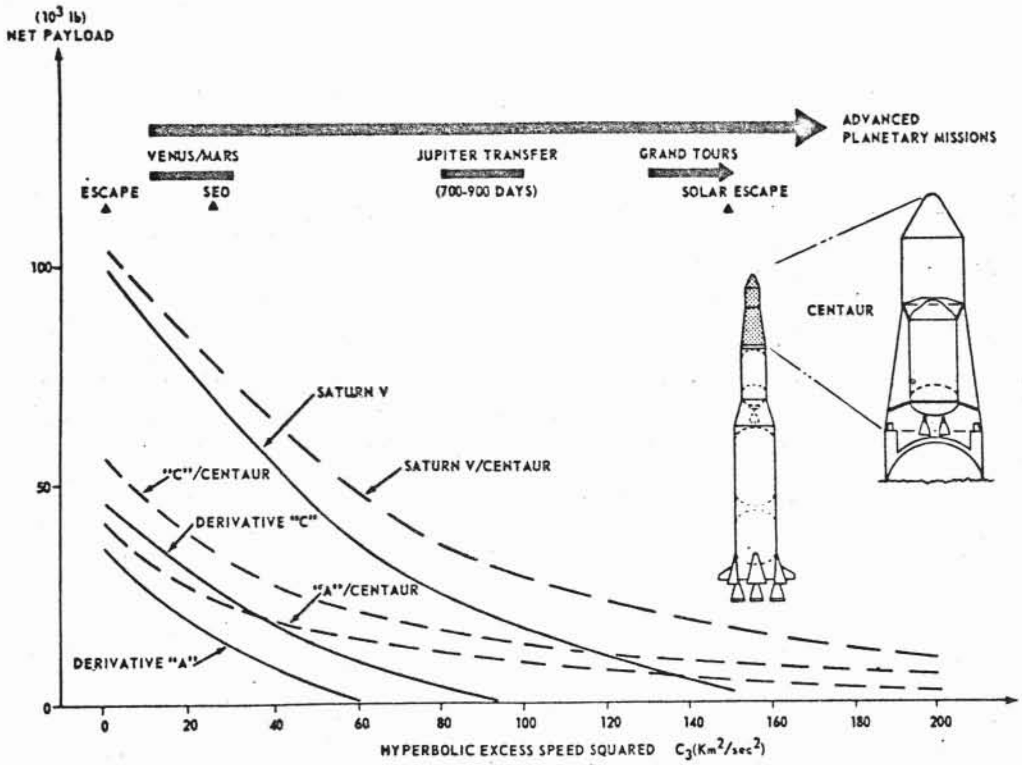
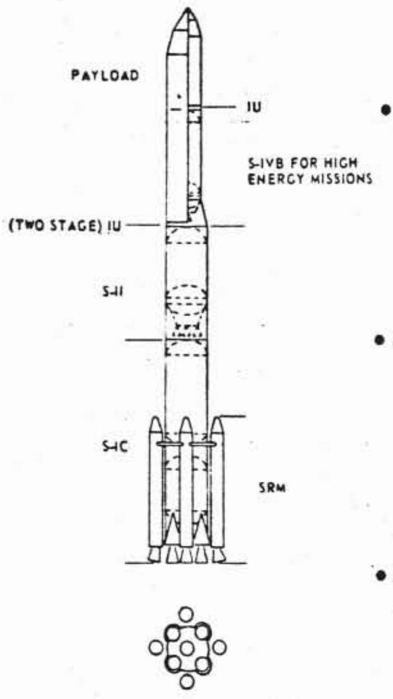


Fig. 10 - Derivative "A" and "C" performance comparison



- PAYLOAD

	LEO
• LUNAR BASE	CORE 244,000
• NUCLEAR MODULES	W 120" SRM 380,000
• PLANETARY LANDING	W 156" SRM 495,000
	W 260" SRM 720,000

- MAJOR CHARACTERISTICS

  BASED ON DESIGN GOALS

  COMMON CORE CONCEPT. CORE VEHICLE ALONE OR WITH TWO OR FOUR SRM AS REQUIRED FOR THRUST AUGMENTATION

  ENCOMPASSES DERIVATIVES "A" "B" AND "C"

  S-IC ONLY STAGE WITH INCREASED PROPELLANT CAPACITY.

- AVAILABILITY (COMMON OR INDEPENDENT DEVELOPMENT)

  EAD 40 MONTHS AFTER ATP

Fig. 11 - "D" derivative, the uprating step

when modifications are incorporated into the common core elements.

3. The payload increase over the present Saturn V capability should be large.

MSFC contracted and in-house studies have demonstrated the feasibility of uprating the Saturn V vehicle by using solid rocket motor (SRM) strap-ons for boost assist. The significant LEO capabilities indicated in Figure 11 are achievable with moderate changes to the standard vehicle, consisting of a lengthened first stage, structural strengthening of all stages, and attachments for the SRMs. The tremendous capability of these configurations (using a three-stage core) is appreciated when one considers a payload of 190,000 pounds

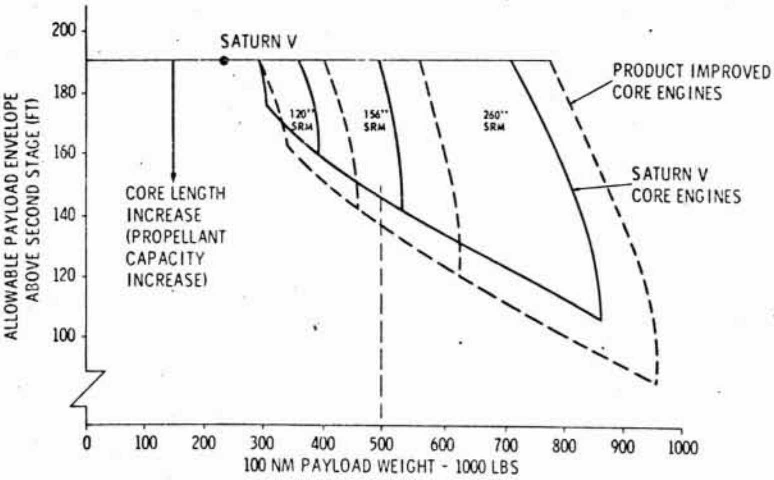


Fig. 12 - Launch vehicle/payload matching chart, uprated Saturn V 2-stage ("D" derivative with SRM) Ref. 10

injected into a 72 hour lunar transfer trajectory by the vehicle with four 3-segment 156-inch-diameter SRM strap-ons.

The first design goal - maximum payload envelope - should be given careful consideration. Trade-offs between the launch vehicle payload weight and length constraints for the uprated two-stage Saturn V are shown on the launch vehicle/payload matching chart in Figure 12. The data are based on maintaining a total vehicle height of 410 feet imposed by the KSC VAB restraint. The allowable uprated Saturn V payload length capability is plotted as a function of payload capability obtained with strap-on solid rocket motor (SRM) size and core vehicle propellant capacity. If the core vehicle length is not increased for the uprating step, 192 feet are available for payload without exceeding the 410-foot limit of the VAB. Payload to the right of the two-stage Saturn V point results from increased SRM propellant weight with two or four 120-inch, 156-inch or 260-inch-diameter strap-on solid rocket motors. Other points on the line would represent design variations in SRM configuration parameters such as burntime.

For any strap-on motor weight, the payload can be increased by increasing basic Saturn V or common core propellant capacity. For example, when four 120-inch-diameter SRMs are strapped on to the core vehicle, the payload weight can be further increased by adding core length up to 42 feet where a constrained optimum occurs. Any additional core length beyond that point would show no increase in payload. The locus of these optimums for each SRM forms the lower boundary of the enclosed area.

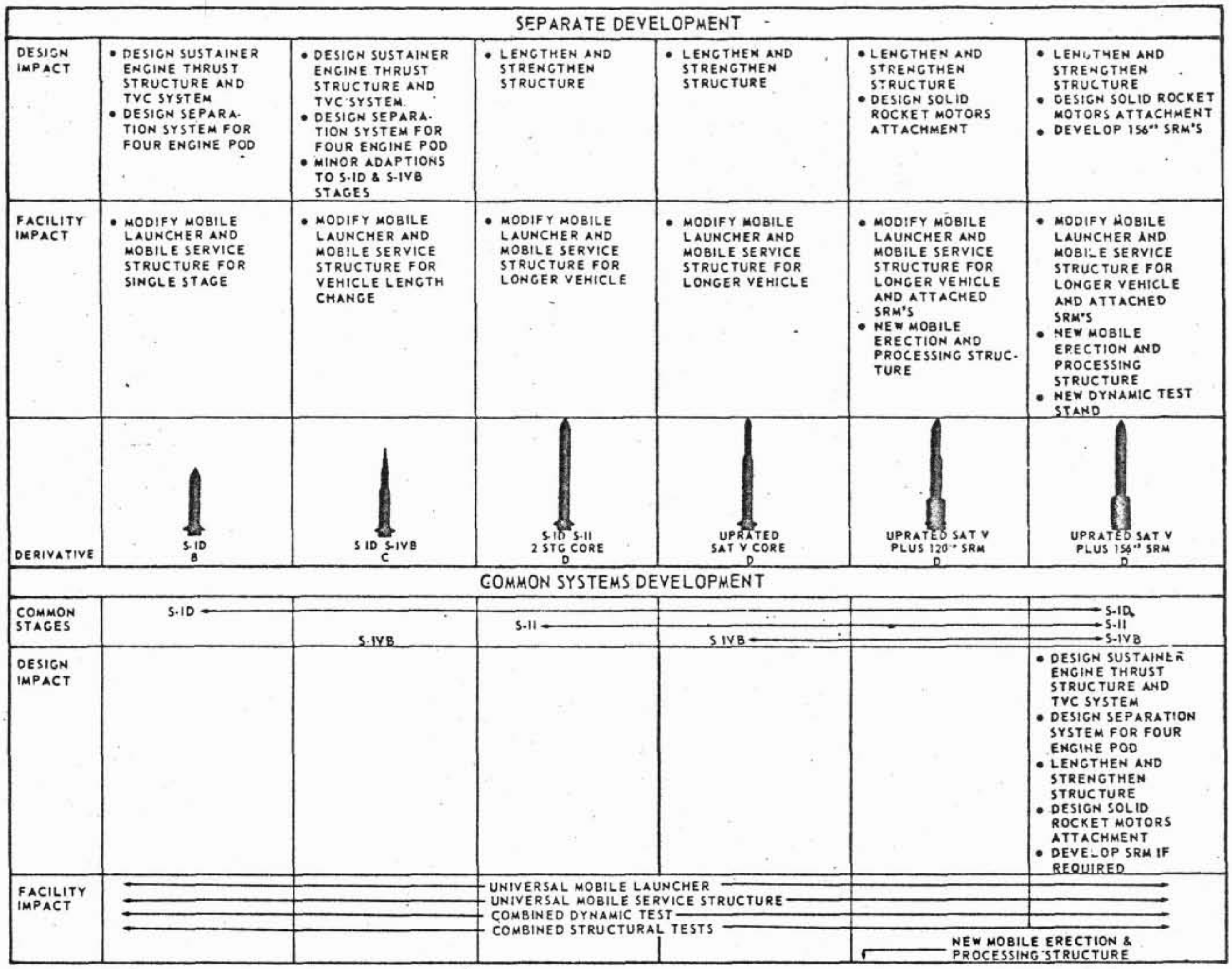
Payload capability of the vehicle can be further increased by uprating the liquid engine(s) in the common core vehicle. The dashed lines shown on the chart represent payload capability with 1.8-million-pound-thrust F-1 engines in the S-IC first stage and J-2S engines in the S-II second stage. The area between the dashed and the solid lines for a given SRM strap-on weight represents partial core engine uprating.

Figure 12 then represents a map of the total spectrum of Saturn V uprating using strap-on solid rocket motors. Many specific points on this map have been studied in detail by stage contractors under MSFC contracts; however, the feasibility of an uprating program utilizing a common core and minimizing launch facilities impacts (evolutionary systems development) has not been fully explored. If the fleet of Saturn V evolutionary launch vehicles utilizing common core elements is determined feasible, then this fleet, its launch facility requirements, mission applications, and their interactions should be studied as an integrated activity.

The second design goal - a common core - would open the door to the evolutionary combined development of a family of derivative vehicle. For uprated vehicles, an evolutionary system development should be used where all derivative vehicles of the family are designed and developed simultaneously to withstand the most demanding mission requirements forecasted. The entire family is designed to use common stages. With the evolutionary development approach, the baseline vehicle should be a strengthened Saturn V core with increased propellant capacity and four strap-on motors for boost assist. The S-ID single-stage-to-orbit mode of operation for the first stage ("B" derivative) would be incorporated simultaneously with the core uprating to increase the launch system flexibility.

The evolutionary derivative fleet would consist of the S-ID single-stage-to-orbit vehicle, and S-ID/S-IVB, the common core (two and three) stage vehicle, and the common core with two and four strap-on solid rocket motors. The payload range of such a fleet could extend from 50,000 pounds to over 700,000 pounds to low earth orbit, depending upon the degree of uprating required. Injection stages could be used with the derivative vehicles to increase their high-energy payload capability.

The third design goal - a large payload increase - must be tempered somewhat to satisfy the other design objectives. A recently completed study indicated the



	SEPARATE DEVELOPMENT					
DESIGN IMPACT	• DESIGN SUSTAINER ENGINE THRUST STRUCTURE AND TVC SYSTEM • DESIGN SEPARATION SYSTEM FOR FOUR ENGINE POD	• DESIGN SUSTAINER ENGINE THRUST STRUCTURE AND TVC SYSTEM. • DESIGN SEPARATION SYSTEM FOR FOUR ENGINE POD • MINOR ADAPTIONS TO S-ID & S-IVB STAGES	• LENGTHEN AND STRENGTHEN STRUCTURE	• LENGTHEN AND STRENGTHEN STRUCTURE	• LENGTHEN AND STRENGTHEN STRUCTURE • DESIGN SOLID ROCKET MOTORS ATTACHMENT	• LENGTHEN AND STRENGTHEN STRUCTURE • DESIGN SOLID ROCKET MOTORS ATTACHMENT • DEVELOP 156" SRM'S
FACILITY IMPACT	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR SINGLE STAGE	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR VEHICLE LENGTH CHANGE	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR LONGER VEHICLE	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR LONGER VEHICLE	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR LONGER VEHICLE AND ATTACHED SRM'S • NEW MOBILE ERECTION AND PROCESSING STRUCTURE	• MODIFY MOBILE LAUNCHER AND MOBILE SERVICE STRUCTURE FOR LONGER VEHICLE AND ATTACHED SRM'S • NEW MOBILE ERECTION AND PROCESSING STRUCTURE • NEW DYNAMIC TEST STAND
DERIVATIVE	S-ID B	S ID S-IVB C	S-ID S-II 2 STG CORE D	UPRATED SAT V CORE D	UPRATED SAT V PLUS 120" SRM D	UPRATED SAT V PLUS 156" SRM D

	COMMON SYSTEMS DEVELOPMENT					
COMMON STAGES	S-ID ←	S-IVB	S-II ←	S IVB ←		→ S-ID → S-II → S-IVB
DESIGN IMPACT						• DESIGN SUSTAINER ENGINE THRUST STRUCTURE AND TVC SYSTEM • DESIGN SEPARATION SYSTEM FOR FOUR ENGINE POD • LENGTHEN AND STRENGTHEN STRUCTURE • DESIGN SOLID ROCKET MOTORS ATTACHMENT • DEVELOP SRM IF REQUIRED
FACILITY IMPACT			UNIVERSAL MOBILE LAUNCHER UNIVERSAL MOBILE SERVICE STRUCTURE COMBINED DYNAMIC TEST COMBINED STRUCTURAL TESTS			NEW MOBILE ERECTION & PROCESSING STRUCTURE

Fig. 13 - Vehicle design commonality and impact

feasibility of increasing the Saturn V capability by using four strap-on 260-inch-diameter solid rocket motors, both in a zero-stage and boost-assist mode; however, the study further emphasized the requirements for large launch facility and vehicle impacts.

Manned interplanetary mission studies have indicated a LEO payload requirement in the 500,000-pound range. This capability is demonstrated in Figure 12 as being achievable by a Saturn V with or without increased propellant capacity plus four 156-inch-diameter strap-on SRMs. This requirement, in conjunction with the minimal launch facility and vehicle impact associated with the common core design concept for uprating to this payload range, supplies the rationale for not extending Saturn V derivatives past the presently projected requirements.

If the "D" derivative development is approached with these design goals in mind, an "open-ended" evolutionary fleet of future vehicles can be developed for minimum total program cost. Whether the above uprated configuration is developed independently or as in the preferred evolutionary common core concept, the earliest availability date is 40 months after ATP date.

DESIGN COMMONALITY AND IMPACT SUMMARY

Figure 13 summarizes the vehicle and facilities design commonality and impact. The chart is arranged in terms of separate systems development (upper half) and combined or common systems development (lower half), with each of the derivative vehicles occupying separate columns. Each derivative vehicle displays varying degrees of design and facility impact. The similarity of impact that exists throughout the vehicle fleet should be noted. The commonality aspects of these required modifications lead one to pursue the common systems development. By developing common core stages that reflect the derivative vehicle-peculiar design impacts, a single common systems development can proceed that encompasses the total evolutionary fleet of vehicles. A similar philosophy would be pursued with respect to the facilities. Details for each vehicle are given in the appropriate column of the chart.

- SATURN V CONTINUOUS PROGRAM
  - AT LESS THAN DESIGN OF 6/YR
  - ECONOMY OF LEAST ADDITIONAL COSTS
- EFFECTIVE USE OF FACILITIES AND PERSONNEL
  - PRODUCTION PENALTIES
  - ANNUAL FIXED COSTS
- COSTS MUST CONSIDER
  - SATURN V AND DERIVATIVE VEHICLE MIX
  - LAUNCH RATE OF EACH VEHICLE CLASS
- WHEN UPRATING, DEVELOP ALL VEHICLES SIMULTANEOUSLY

Fig. 14 – The cost picture

THE COST PICTURE

Many of the functions required to produce and launch the Saturn V or derivative vehicles are fixed on an annual basis (plant maintenance, etc.) or fixed by the need to complete a task in a given time (launch crew size, etc.). When the Saturn V production rate is varied and when derivative type vehicles are produced in addition to Saturn V's, the change in unit cost must be appreciated. There is no argument to the economy of making additional use of Saturn V equipment and facilities. For purposes of this paper, we are not assuming any program for any definite period of time for determining costs in order to amortize investment costs over that period. We are, instead, allocating R&D costs as applicable to each derivative configuration based on the economy of commonality in design revisions. The magnitude of the payload capabilities for all candidates tends to discount the slight performance degradation suffered for this concept of open-ended development.

The Saturn V and near-term derivative mix of vehicles will utilize Saturn facilities; no additional launch facilities are required for a traffic rate of six or less derivative vehicles per year.

To provide a reasonable basis for cost comparison of evolutionary derivatives, we have established a baseline program for delivery and launch at KSC of three Saturn V vehicles per year. This three-per-year production rate is based partially on the January 11, 1967 PSAC Report which states in part:

> "At least two Saturn V/Apollo systems per year will be required for continued lunar exploration during the immediate post-Apollo period. We believe a third complete system should also be built annually as a backup, ..." (Ref. 11)

Total cost analyses must consider all the venicles to be produced and launched to satisfy total objectives. Since current planning strongly indicates the production and launch of some quantity of Saturn Vs each year for the next several years, the total cost driving factor is how many additioanl vehicles will be launched. With the below optimum Saturn V annual rate the least additional cost is incurred by adding Saturn V derivative vehicles. This avoids additional annual fixed costs as would be incurred if a non-related vehicle were selected with separate below-optimum production facilities and a separate below-optimum launch complex. In brief, pay one annual fixed production facility cost and one annual fixed launch complex cost, not two of each.

Effective use of production and launch facilities and personnel ensures very economical derivative vehicles. The low production rate penalty for three Saturn Vs per year adds about 20 percent to the hardware cost. Increasing the number of S-IC, S-II and S-IVB stages to six per year eliminates production penalities. Annual fixed costs for Saturn V production facilities are incurred to maintain the production capability. Therefore, for example, the S-IC/S-IVB vehicle production can be added through six per year total by paying only the additional recurring costs. Similar economy is obtained in launch costs, in that Saturn V has paid the fixed annual cost and the S-IC/S-IVBs add only the recurring costs, i.e., propellants and pad refurbishment.

The Saturn V and derivative vehicle mix should be considered with respect to relative total cost and total number of launches per year. Keeping within the established baseline, the total costs for the single- and two-stage derivative vehicles will be incremental unit costs after fixed annual costs are absorbed by the three-stage vehicles.

When vehicles are uprated or when several new vehicles are added, the whole development should be done simultaneously. Considering the cost of DDT&E for the largest vehicles as unity, each additional vehicle DDT&E will add about 10 percent to the cost. The savings from combined structural tests, for example, becomes quite obvious. A major saving is obtained by proportioning the R&D flights for the group of vehicles under simultaneous development, rather than specifying R&D flights for each separate version.

Relative costs of production units and vehicle support activities as a function of required traffic rates are illustrated in Figure 15. The left chart on production rate penalties demonstrates the unit cost increase that results when the production rate decreases below optimum. As previously stated, the production rate of six Saturn V vehicles per year is considered optimum.

The example shows that when the yearly rate increases by one vehicle from 3 units/year to 4 units/year, the total cost increases by 80 percent of the optimum unit cost. Conversely, when the rate decreases the penalty is 20 percent of the 6/year unit cost.

Vehicle support consists of operating the physical plant, communications, inspection,

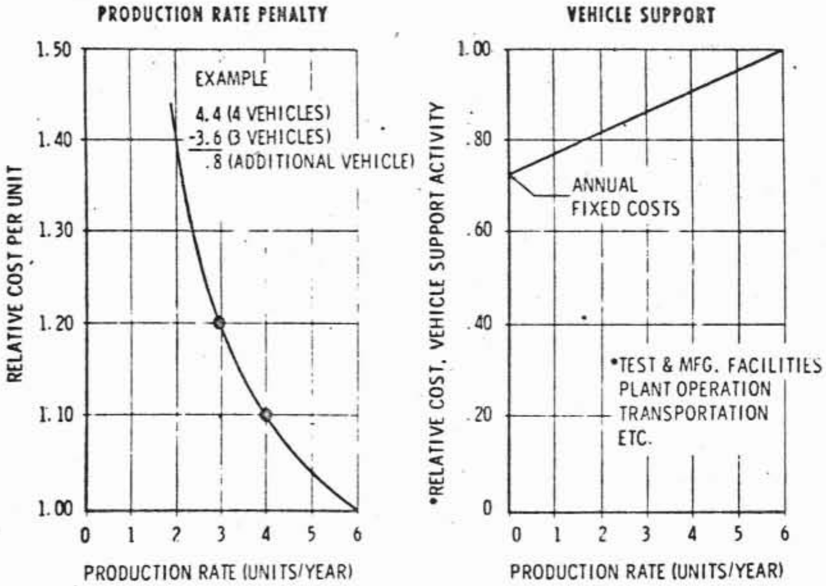


Fig. 15 - Cost factors

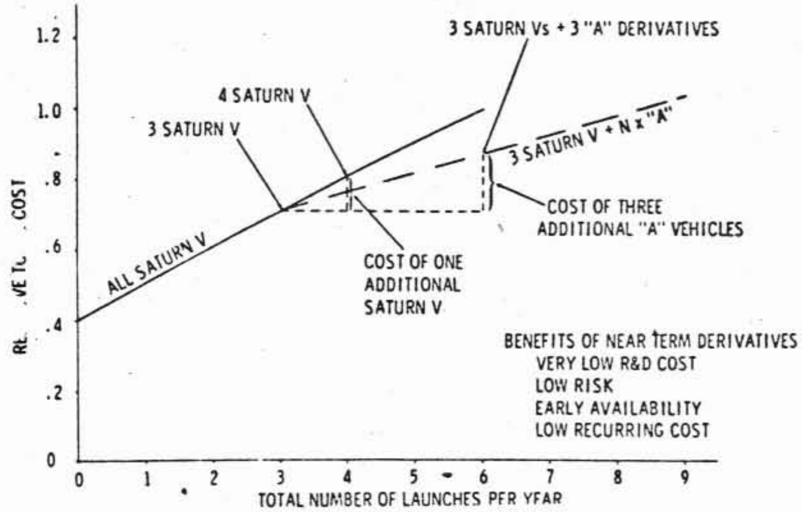


Fig. 16 - Saturn V and "A" derivative (S-IC/S-IVB) vehicles, total cost of typical 10 yr program

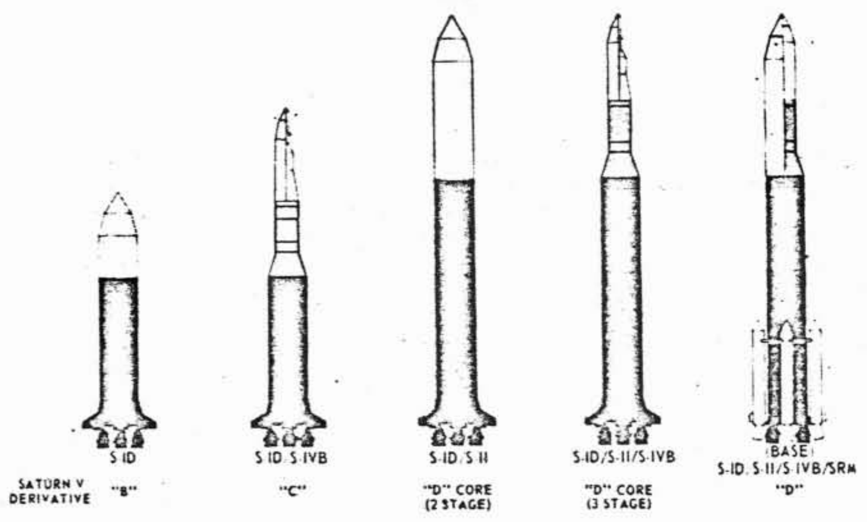
transportation, system integration, and test complexes. Most of these costs are incurred at an annual fixed rate. The annual fixed cost maintains the capability to produce and is independent of production rate. Some costs, such as inspection and system integration tasks, are incurred as a function of the quantity of units produced. The right-hand chart shows that after the annual fixed cost is incurred for the Saturn V program, derivative vehicles can be added for a small additional cost. For example, each additional vehicle adds less than five percent to the total vehicle support cost. Although not included, launch costs show a similar characteristic.

The total cost variation of a typical ten-year program of Saturn V and "A" derivative (S-IC/S-IVB) vehicles is illustrated in Figure 16. The different slopes of the "All Saturn V" line and the "Saturn V plus a number of "A" vehicles line demonstrate this variation with vehicle mix and traffic rate. The unit cost of Saturn Vs decreases as the launch rate increases.

The chart primarily shows that for four or fewer Saturn Vs per year, a quantity of S-IC/S-IVBs could be added for small additional cost. For example, with a program of three Saturn Vs per year, one to six S-IC/S-IVBs could be added for a six-percent increase in cost for each S-IC/S-IVB.

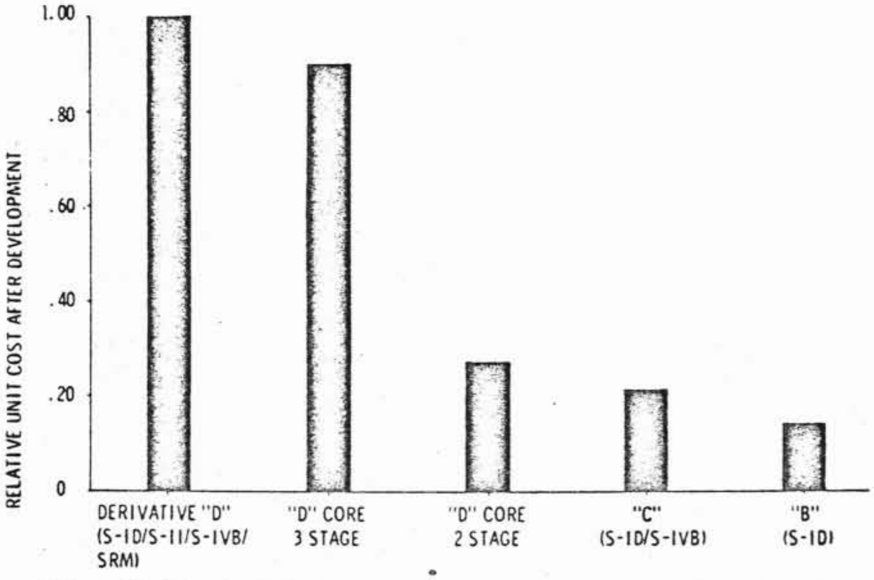
DEVELOPMENT OF THE FLEET

The Saturn V evolutionary family, with development costs for the uprated Saturn V derivatives, is depicted in Figure 17. The various stages are color coded to emphasize the commonality aspects of these vehicles. The requirement for combined development becomes obvious when we see the utilization of common hardware throughout the entire family. The first stage, now designated S-ID, is common to all configurations and the upper stages of the three stage "D" common core are combined separately with this stage to form the "C" and "D" derivatives. The Solid Rocket Motors are also strapped to the S-ID stage for thrust augmentation with a resulting scar weight from the structural attachments causing negligible payload degradation in the other applications.



VEHICLE	SEPARATE DEVELOPMENT DDT&E	SEPARATE DEVELOPMENT R&D FLIGHTS	SEPARATE DEVELOPMENT TOTAL	COMBINED DEVELOPMENT DDT&E	COMBINED DEVELOPMENT R&D FLIGHTS	COMBINED DEVELOPMENT TOTAL
S-ID/S-II/S-IVB/SRM	.50	.50	1.00	.50	.50	1.00
S-ID/S-II/S-IVB	.25	.42	.67	.04	.21	.25
S-ID/S-II	.20	.20	.40	.02	—	02
S-ID/S-IVB	.15	.15	.28	.03	.08	.11
S-ID	.05	.10	.15	.03	.05	.08
TOTAL	1.13	1.37	2.50	.62	.84	1.46

Fig. 17 - Development cost for uprated Saturn V and derivatives



NOTE: INCREMENTAL COSTS FOR 1 AND 2 STAGE VEHICLES AFTER 3 STAGE VEHICLES INCUR THE FIXED COSTS.

Fig. 18 - Operational cost comparison of Saturn V derivative vehicles

The combined development of a family of similar launch vehicles is more economical in many respects than separate developments. Economy is obtained primarily by unified DDT&E, fewer R&D flights, and commonality of hardware.

When developing the evolutionary family, the three-stage vehicle with solid rocket motors would be the baseline. Adaptations and accessory parts kits for the smaller derivative vehicles would be incorporated during the core design. Drawings would contain notations of vehicle applicability. Designs would incorporate the capability for quick adaptation of stages to any of the five configurations.

When a new launch vehicle is introduced, two or more R&D or man-rating flights are needed to establish confidence. If the five vehicles shown, or any other five different vehicles, were developed independently, at least 10 development flights would be needed to prove the design and system integration. A major saving is obtained by proportioning the R&D flights for the group of vehicles under simultaneous development rather than specifying R&D flights for each separate version. The evolutionary family of vehicles would be designed to withstand the most demanding requirements of the group and, with many common components, each test builds confidence in the entire group. The three-stage vehicle with

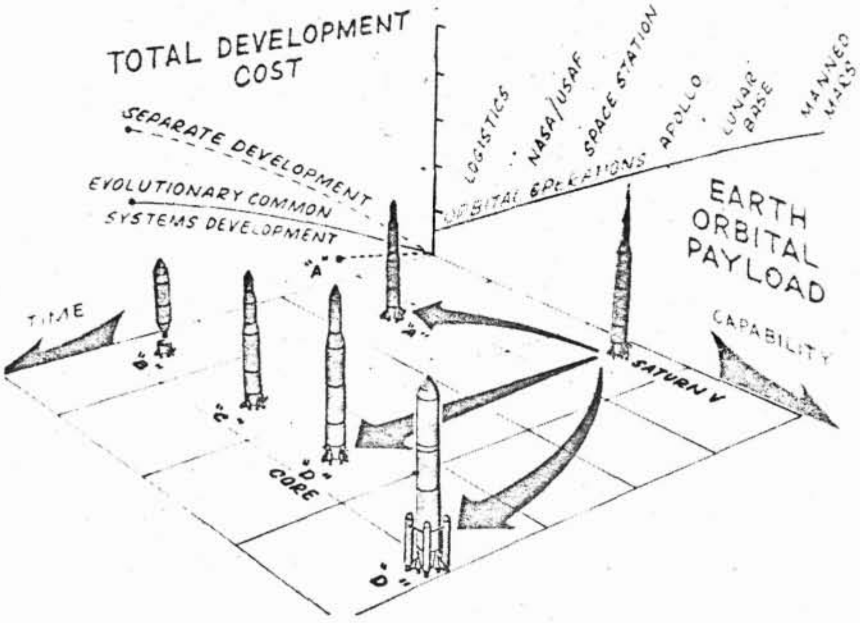


Fig. 19 - Saturn V Derivatives: capabilities, resources, schedule

strap-on solid rocket motors would need two R&D flights to test each component and each interface under the most rigorous conditions. After successful R&D flights of the largest vehicle, the smaller derivative vehicles would need one R&D flight each to check different interfaces and possible anomalies. If the three-stage vehicle without solid rocket motors is tested second, the two-stage version should not require an R&D flight because the only change is a much lighter payload. By simultaneous design and development of all vehicles in the common core family, R&D flights can safely be reduced by approximately 50 percent.

The primary message of this chart is the reduction of total relative development costs from 2.50 to 1.46, or 42 percent, by simultaneous development achieved through the common core concept for Saturn V derivative vehicles.

After the evolutionary family becomes operational the average unit recurring costs that would be incurred are shown on Figure 18. The large three-stage vehicles perform the most demanding tasks and incur the annual fixed costs for maintaining the launch capability. For missions of lesser payloads the smaller vehicles enjoy the economies of commonality and span the payload spectrum. As shown, the single-stage S-ID costs only 18 percent as much as the baseline vehicle, the S-ID/S-IVB costs 23 percent as much, and the two-stage core vehicle 26 percent.

CONCLUSIONS

If the assumption that a three-per-year roduction rate for Saturn V appears to be reasonable for planning purposes, then, obviously, Saturn V facilities and operations esigned for a six-per-year production rate are used inefficiently at this lower production rate. When Saturn V elements are utilized as derivative vehicles to complete the payload spectrum between the Saturn IB and mission requirements beyond the Saturn V, more efficient use of these facilities and operations results. Because this approach is very economical, the derivative vehicle program costs become highly competitive for any selected payload requirement.

Using the S-ID both as a stage and one-half to orbit and, as it becomes available, a replacement for the S-IC in the stable of Saturn V derivative vehicles increases the flexibility and capability in the intermediate payload range. The payload flexibility obtained by installing engines, solid rocket motors, or propellants peculiar to each payload and mission requirement is a distinct advantage of the evolutionary scheme; however, the major advantage of the evolutionary concept is the commonality of design revision for all suggested derivative systems. A redesigned thrust structure with scar attachments for SRM strap-ons and a strengthened Saturn V core essentially implement the derivative systems that evolve from our present man-rated system. The single R&D expenditure, amortized over this stable of vehicles, places each derivative in a favorable competitive position for its point on the complete payload spectrum.

The capability for these Saturn Derivative evolutionary vehicles to span the earth orbital payload spectrum from 50,000 to 500,000 pounds is illustrated in Figure 19. Starting with the present operational vehicle, it is possible to acquire a near-term earth orbit logistics system if we pursue the path of the "A" derivative. The route of separate development of derivative "D" is not recommended for the large payload capability required of manned planetary exploration. The most economical and straightforward evolutionary common systems development is the recommended path of advancement for versatility, efficiency, and ability to meet all the potential mission requirements. This exploitation of the commonality concept is portrayed by derivatives "B", "C", and "D" covering the payload spectrum for minimum total development cost.

We have described the capability and versatility of the Saturn V launch vehicle system to perform earth orbital and high energy missions. In addition, we have identified a near term, low R&D cost, highly reliable, low recurring/cost "A" derivative launch vehicle. Finally, we have developed an evolutionary common core concept that can be initiated through the "D" derivative development program. This concept demonstrates the economy of choosing proper design goals and utilizing combined developments to achieve an open-ended evolutionary fleet of future launch vehicles.

In the long run, the versatility and utility of the Saturn V launch vehicle may prove to be of even greater significance to the United States than its role as the "moon rocket," or as a competitor with Soviet launch vehicles; and, the evolutionary family of Saturn V derivatives presented herein would truly comprise an all-purpose family of space launch vehicles.

ABBREVIATIONS

Std	Standard
Sat	Saturn
S-IC	First Stage of Saturn V
S-II	Second Stage of Saturn V
S-IVB	Third Stage of Saturn V
IU	Instrument Unit
LEO	Low Earth Orbit (100 n. mi. circular)
SEO	Synchronous Earth Orbit
SRM	Solid Rocket Motor
EAD	Earliest Availability Date
ATP	Authority to Proceed
N. Mi.	Nautical Mile
C_3	Energy Parameter (Km^2/Sec^2)
R&D	Research and Development
DDT&E	Design Development Test and Engineering
lb	Pound
Km	Kilometer
Sec	Second
SLA	Saturn LEM Adapter
VAB	Vertical Assembly Building

REFERENCES

1. A. G. Orillion and R. D. Scott, "Selected Methods for Uprating Saturn Vehicles," paper presented at SAE Advanced Launch Vehicle and Propulsion System Conference, Huntsville, Alabama, June 1966.

2. R. G. Toelle, "A Performance Study for the Application of the Saturn V to High Energy Earth Escape Mission," NASA Technical Memorandum X-53639, July 31, 1967.

3. J. Martin, "Saturn V Growth and Flexibility," Document Number D5-13352, The Boeing Company, March 31, 1967.

4. L. Lane, "Orbital Launch Vehicles for the 1970's," Document Number D-13366, The Boeing Company, July 12, 1967.

5. NASA/George C. Marshall Space Flight Center, Contract NAS8-20265, Studies of "Improved Saturn V Vehicles and Intermediate Payload Saturn Vehicles (P-115) Final Report," North American Aviation, Inc. S&ID, October 1966.

6. NASA/George C. Marshall Space Flight Center, Contract NAS8-20266, "Studies of Improved Saturn V Vehicles and Intermediate Payload Saturn Vehicles (P-115) Final Report," The Boeing Company, October 1966.

7. NASA/George C. Marshall Space Flight Center, Contract NAS8-21105, "Final Report-Saturn V Vehicle with 260" Diameter Solid Motor Study," The Boeing Company, December 18, 1967.

8. NASA/John F. Kennedy Space Center, Contract NAS10-3547, "Study of Launch Facilities for Improved Saturn - Phase III Final Report," Martin Company Document CR-66-41 (Volume III), December 1966.

9. NASA/George C. Marshall Space Flight Center, Contract NAS8-18025, "Manned Planetary Flyby Missions Based on Saturn/Apollo Systems Final Report," North American Aviation, Inc. S&ID, August 1967.

10. J. Dollard, "Common Nuclear Propulsion Module Approach to Space Exploration," Document Number D5-13425, The Boeing Company, January 1968.

11. President's Scientific Advisory Committee (PSAC) Report, January 11, 1967.