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SPACE AGE MANAGEMENT

OR

MAINTENANGE OF TECHNICAL CAPABILITY DURING A PERIOD OF RETRENCHMENT

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Summary

On January 31st of this year the United States celebrated its tenth anniversary in space. In just one decade we have seen our space program climb from an humble beginning (a 30.8-pound payload put into orbit with a jury-rigged rocket) to extra-vehicular-activity and the tremendous Saturn V vehicle capable of putting 250,000 pounds into low earth orbit. We have seen it grow from a "quick and dirty" operation to a program which at its peak had approximately 380,000 industrial employees in excess of $5.0 billion per year. The marshalling of this great management and technological team generated many "growing pains." A few years ago the hue and cry was, "Where are we going to get sufficient people with scientific knowledge and drive to implement the space program?" Industry, sometimes reluctantly, was pressed into tasks which required managerial and technical skills beyond those they then possessed.

Judging from the success of recent launches, one might conclude that the most difficult problems are past. But just as NASA experienced many "growing pains" in reaching the peak effort in 1965, it is now finding that the "shrinkage pains" are as severe. NASA is reducing its nationwide employment by 4,000 to 5,000 people per month. By July of this year industrial employment will have been reduced over 1/3 (to about 240,000 people) and the number of firms will have been reduced to about 15,000.

Since the engines have the longest leadtime of anything in the Saturn vehicles, their activity has progressed further down the retrenchment curve than other facets of the system, as seen in Figure 1. The management decisions to cope with this shrinking base of activity have already been implemented. Other program segments must now cross these same bridges.

The Problem

As the Apollo Program declines in personnel and expenditures, Government and Industry managers must tailor the reductions in accordance with many influence factors - the most formidable of these is the budget. In the light of the overall budget pressure, what priority should be given to sustaining engineering? On the one hand the program dictates a need for a competent engineering staff to keep complex, hand-built vehicles flying, while on the other hand the ever-present budget pressure and the intermittent nature of the demand for this skill make it difficult and expensive to provide.

An effective answer to this paradox presents a real challenge to NASA management today. The experience of Marshall Space Flight Center's (MSFC) engines and the approach used to buffer an otherwise rapid decay in engineering capability provide a relevant case study in the management of engineering capability in a declining program.

Background

For perspective, note the lead times and phasing of a typical rocket engine development program in relation to the overall vehicle program (Figure 2) -- in this case the F-1 engine. The Flight Rating Test (FRT) was completed two and one-half years prior to the time engines of that configuration flew in AS-501. The same thing is true in regard to the Qual II configuration, which is the configuration qualified for the lunar mission. But as far as the engine development personnel were concerned, the bulk of the design effort and the challenge were gone when the engine proved itself in qualification testing. Upon completion of qual testing, the design and development personnel strength began to phase down sharply, even though the flight integrity of the engine was not yet established.

This gave rise to a basic question: After engine qualification, where and how far is it prudent to cut back the technical capability, and still provide adequate technical support for the flight test and operational phases of the program?

Precedences exist from which we may secure some guidance. For example, Pratt & Whitney has found that their sustaining engineering effort following the first qualification of a jet engine is approximately equal to the total development cost experienced prior to that first qualification. Since this experience has evolved from a competitive environment in which the company must make a profit to survive, it is considered highly credible.

After engine system qualification in the Redstone program, a certain problem-solving capability was provided in terms of the hardware and test stands needed to solve problems, but little planning was done toward a balanced program from an engineering standpoint. Well into the flight program a serious injector problem developed. When the sustaining engineering team began to tackle this problem, it was readily apparent that the needed engine hardware and test stands were available but that most of the capable people had left the program. Consequently, the technical team was of insufficient stature to handle the problem in a timely fashion. Fortunately, many of the engineers who had left the Redstone engine project were working on other projects at the contractor's plant, and the contractor was able to rebuild the team by transferring some of the people back into the Redstone engine project. Even so, it took about 90 days for them to get "up to speed" on the project again. From this Redstone incident a lot was learned about how "not to do it." Consequently, in the Jupiter program an evolution was begun which has resulted in what is today a very flexible sustaining engineering effort which has paid substantial dividends in the Apollo program. Not only has the sustaining engineering provided the direct benefit of rapid response to manufacturing and field problems, but it has also produced many important by-products.

An Approach to Sustaining Engineering

As is true for any sophisticated piece of machinery, a liquid rocket engine which operates under dynamic conditions, handles a variety of fluids from cryogenics to 6000°F gases, utilizes a wide range of mechanical devices from sophisticated valves to high speed rotating machinery, and is produced in small quantities, will experience field problems. The primary objective of, and for that matter the primary justification for a sustaining engineering program, is to provide the capability to solve manufacturing, field and flight problems. Our experience in the Redstone, Jupiter, and Saturn programs, provides a basis for estimating the frequency and magnitude of problems relative to hardware maturity. For example, Figure 3 depicts the frequency of major problems versus key milestones for the H-1 project. Experience on the RL-10, F-1 and J-2 is similar. The uncertainty of when a problem will arise dictates the continuous maintenance of a capability to cope with these problems. One finds that based on experience he is able to predict the aggregate needs of the sustaining engineering effort reasonably well. However, the demand for these resources is intermittent, erratic and cyclic. This is qualitatively illustrated by comparing Figures 4 and 5. Figure 4 shows the level of sustaining engineering to be provided. However, going a bit deeper, one realizes that the effort will be required as shown in Figure 5. Paramount to an effective sustaining engineering program is the efficient programming of the most important improvement tasks between the cycles and effort required by field and flight problems.

The approach used with the Saturn booster engines has been to divide the work into three basic categories:

(1) <u>Operational Support</u>

(2) <u>Elimination of Potential Failure Modes and Operational Restrictions</u>

(3) <u>Upgrading of the Products</u>

Some elaboration of these categories is in order.

Operations Support connotes that portion of the sustaining engineering which directly supports the operational phases of the Saturn program; i. e., the engineering support needed for an on-going launch vehicle program. The bulk of the effort is utilized to explain and find solutions to engine problems which could impede or stop the delivery of engines, or could impact stage assembly, test or launch. To this primary task is added certain auxiliary supporting tasks such as analysis of engine data from stage ground and flight tests, reliability assessment, flight worthiness verification testing and coordination with the stage contractor on interface matters and engineering change proposals.

Elimination of Potential Failure Modes and Operational Restrictions denotes that work which is done on those components and procedures which have never caused a failure, but which have excessive operational restrictions, are difficult to check out, or based on analysis are known to be a potential failure mode.

Upgrading of the Product includes those tasks which are directed toward making significant changes in the basic configuration to increase performance or to simplify the engine. One of the primary purposes of these tasks is to provide challenging work to keep creative and energetic people on the program and to keep them proficient. Though the percentage of the total sustaining engineering program denoted to this activity is small, it has a very direct and significant bearing on our ability to adequately support an on-going flight program; to wit, the Redstone experience earlier.

The entire resources of the sustaining engineering program must be available to solve problems which could seriously impede the overall launch vehicle program. Therefore, priorities are assigned to the work under the sustaining engineering as follows:

Priority 1: Operational Support

Priority 2: Reduction in Potential Failure Modes and Operational Restrictions

Priority 3: Upgrading of the Product

Referring to Figure 6, it is seen that the Priority 2 and 3 effort is used to fill the "valleys" between the peak loads in the Operational Support. Thus, in addition to providing the more challenging tasks, the Priority 2 and 3 effort is in effect a pool of talent which is available to satisfy the high demand periods in the Operational Support. Incidentally, it should be noted that the peaks and valleys do not occur in all of the specialties simultaneously. For example, a turbopump problem and an injector problem would not be expected to occur simultaneously. Therefore, Figure 5 more nearly depicts what happens in a given specialty group, rather than in the composite. Over the years, in terms of manhours, about 70% of the effort has gone to Priority 1, 20% to Priority 2, and 10% to Priority 3.

The effectiveness of the sustaining engineering program is directly related to the comprehensiveness of the planning. The planning must cover the spectrum. It must consider not only each technical specialty which is to be maintained, but also the anticipated testing load (both for components and engines) and the test hardware needed (including test bed engine systems). It must also consider the time phasing of and the balance between each of these. The importance of a thorough and detailed plan cannot be over-emphasized.

The Results

This priority system has proven to be rather successful in achieving our two primary goals - the maintenance of a highly qualified cadre of technical people and providing timely solutions to "program stopper" problems. Two examples illustrate the quick response to problems:

In June of 1964, stress corrosion cracks were found in the LOX domes on the H-1 engines which were installed in Saturn vehicle SA-7. The vehicle was at KSC in preparation for launch. Fortunately the problem as related to the alloy and heat treat had been detected earlier, though the severity was not clearly known. Under Priority 2 effort a dome with an improved material had been developed and had been incorporated as an in-line change in the H-1. Consequently, the manufacturing pipe line was filled with the improved domes. As a result, all eight engines were removed from the stage, the domes replaced, and the engines retested and reinstalled in the vehicle with a resultant launch slip of about two weeks. Since this dome has a lead time of 11 months, not including the needed R&D, the flight program could have been seriously impacted had the problem not been identified and solved many months before it was encountered in the field.

A second problem, different in nature, but one which also created a launch restraint concerns a redundant cutoff for the F-1 engine. As originally designed the first stage of the Saturn V was to use the stage prevalves as a redundant cutoff for the F-1 engines. Rather late in the Saturn V program, a test was conducted to verify that this system would work. The prevalves were closed while the engine was running, the pumps went into deep cavitation with a resultant explosion in the LOX pump. The problem was resolved by adding redundant shut-down capability within the engine. A system which was originally designed for ground test was modified and qualified for flight (in both the lab and on engine systems) in six weeks. Thus, there was no impact on the flight of the first Saturn V.

But the real proof of the success of any sustaining engineering lays in the flight record (Figure 7). In the Saturn program through February of this year, 173 engines had been flown with one engine failure. On the SA-6 flight in the Saturn I program an H-1 engine cut off six seconds early. The problem was diagnosed to be a gear failure in the turbopump gear train. This gear had already been identified as a potential problem in the sustaining engineering (under Priority 2) and an improved gear had been developed and put into production. As a matter of fact, the engines in the next vehicle (SA-7) had the better gears, so no hardware changes or retrofits were needed and no costly delays were encountered.

In addition to the direct contributions to the on-going program, there are many by-products which fall out of the effort. Rocket engines are, as everyone knows, very expensive. New engine development programs are long and costly. It is, therefore, sound management to get the maximum "mileage" possible from existing engines. Some of the biggest fall-outs from sustaining engineering are realized by "stretching" the design of existing engines. As an example, the predecessor to the H-1 engine was rated at 135,000 pounds thrust. It was uprated to 142,000, and then to 150,000 pounds thrust. A repackaged version of the same engine (S-3) was utilized at 165,000 pounds thrust, under the new name, the H-1 engine. It was followed by further upratings which operated at 188,000, 200,000, and finally today at 205,000 pounds thrust.

The significance of these upratings can be best illustrated by looking at the payload gain achieved by each of our engines as we continued to refine and improve the basic configuration (Figures 8-12). Our experience to-date leaves no doubt that even considering the vehicle modification costs, this is the cheapest method of getting additional payload capacity, on a cost per pound in orbit basis. Of greater significance, the Saturn V needs the additional capacity to put a man on the moon in this decade.

Another by-product which may be less tangible in quantative sense centers around the "criticality" of components in the Saturn vehicle. Figure 13 shows that on Saturn 501 the engines represented almost half of the total criticality of the vehicle. Criticality as used here is an empirical measure of the reliability of the item and the consequences of its failure with respect to mission success. Significant benefits are derived in terms of mission success, by keeping a well-qualified team focusing on a better understanding of and ways to improve the single most critical item on each stage. Sustaining engineering provides the means to break the status-quo psychology and open the door to new ideas, which in the long run significantly reduce flight failure risks.

Conclusions and Prospectus

A healthy sustaining engineering program, subsequent to engine system qualification, has been a part of the normal mode of operation for several years at MSFC. Although the program exists basically to provide fast responses to manufacturing, field and flight problems, it is also specifically structured to insure maintenance of a highly qualified and balanced engineering team by providing secondary tasks which are pursued during the lull between problems. A similar approach is recommended for all who provide complex, state-of-the-art equipment where schedules and performance are critical. With the 70%-20%-10% split between "fire fighting," "insurance," and "future" respectively, we have achieved not only the basic objective of rapid response to problems but also have been able to more fully exploit the very significant investment in the engines. This approach has contributed directly and substantially to an unprecedented flight record for large vehicles and a much needed payload margin at a relatively low cost.

The future, however, must be viewed in the cold light of declining resources. The pressure is on from all quarters to reduce spending. Sustaining engineering, as described here, has worked well, but how far can it be cut before the integrity of the engineering team is lost? It appears that the "threshhold program" for an engine is one in which the level of activity is sized around one engine system test stand operating one shift. On an average this would provide the engineering staff with about two or three engine system tests a week for verification of "fixes" for problem, evaluation of updated components, etc. Just how fast one should reduce to this threshhold program remains an open question. Certainly not until the lunar mission is accomplished.

The development of the booster engines (the H-1, RL-10, F-1, and J-2) used in the Saturn launch vehicle were begun in the two-year period from the Fall of 1958 to the Fall of 1960, well in advance of any of the Saturn stages which eventually used them. Therefore the Saturn program was built around these engines.

The next large launch vehicles will also be built around these engines, or they will be a long time oming - because except for the nuclear engine ere are no others. The F-1 and J-2 engines ave sufficient growth potential, with relatively straight-forward engineering changes, to provide a 20% increase in the Saturn V payload. The level of effort in sustaining engineering will determine when and if these potential gains are to be realized. It seems prudent that these engines should be uprated to the fullest in order to capitalize on the rather substantial investment in their development, and to help fill the gap between now and the day when a new generation of rocket engines is available.

COMPARISON OF
SATURN BOOSTER ENGINES AND APOLLO PROGRAM
DIRECT CONTRACTOR MANPOWER

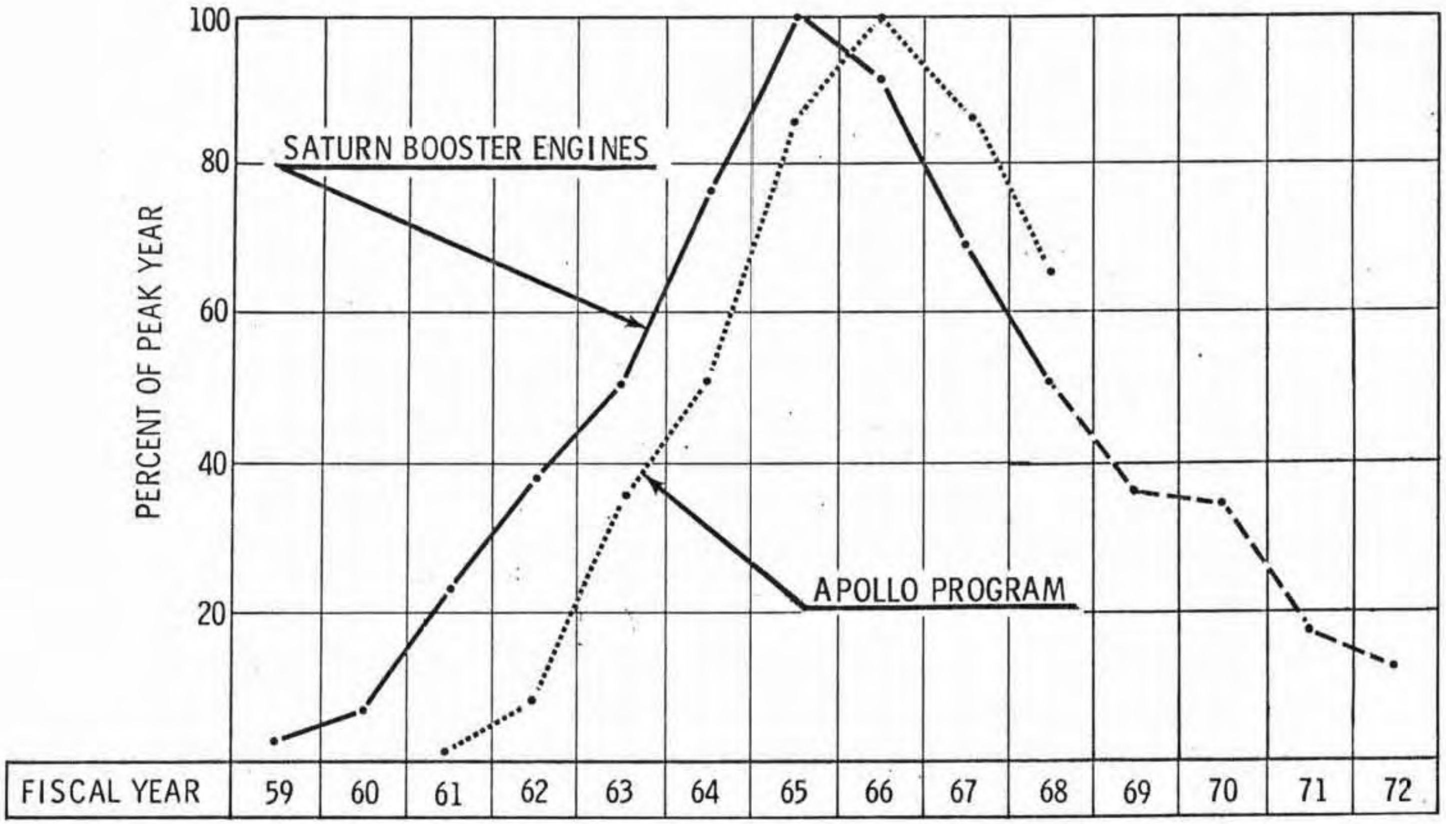


Figure 1

F-1 ENGINE PROGRAM MILESTONES

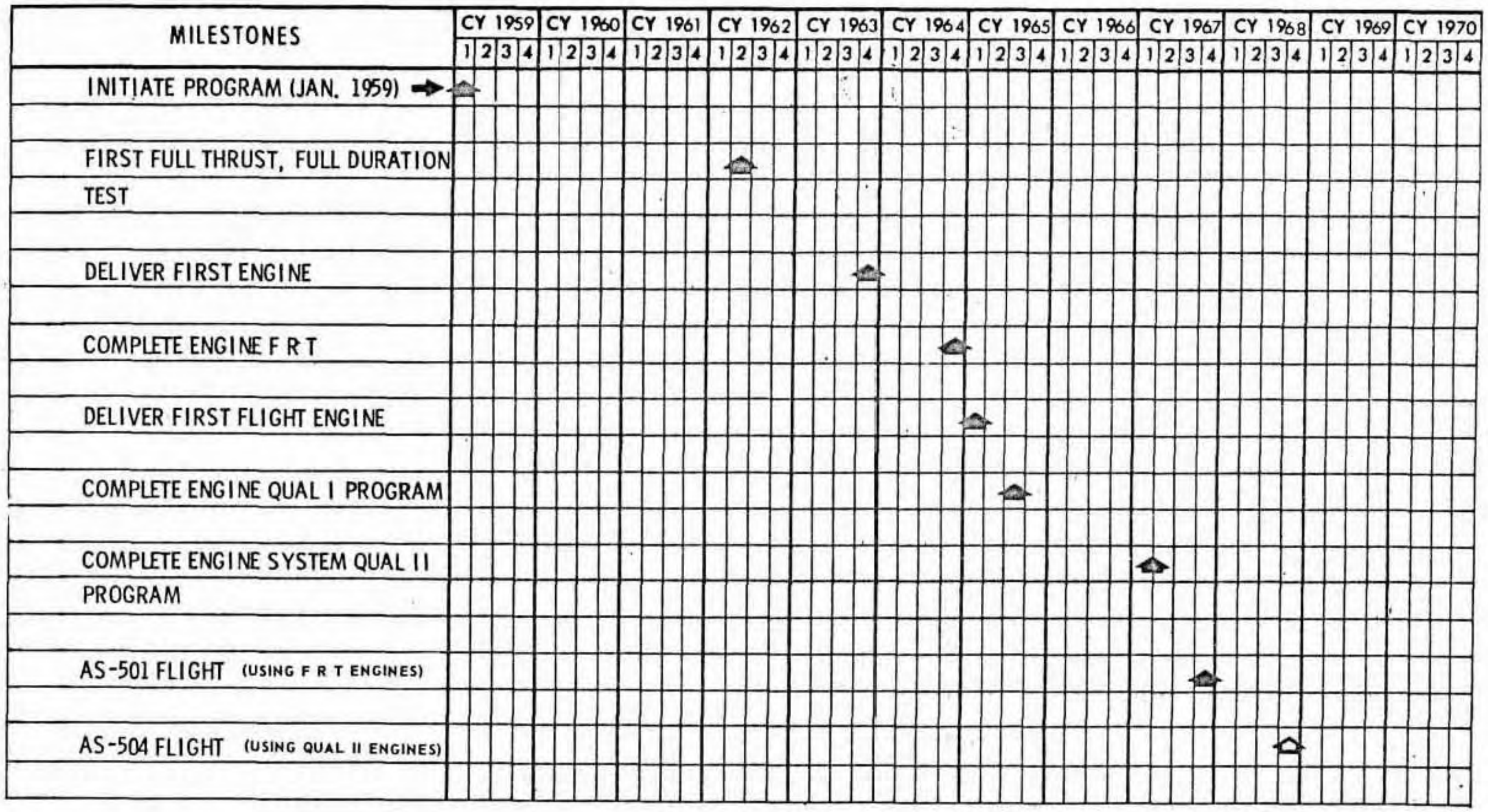


Figure 2

H-1 ENGINE PROGRAM
FREQUENCY OF PROBLEMS VS KEY MILESTONES

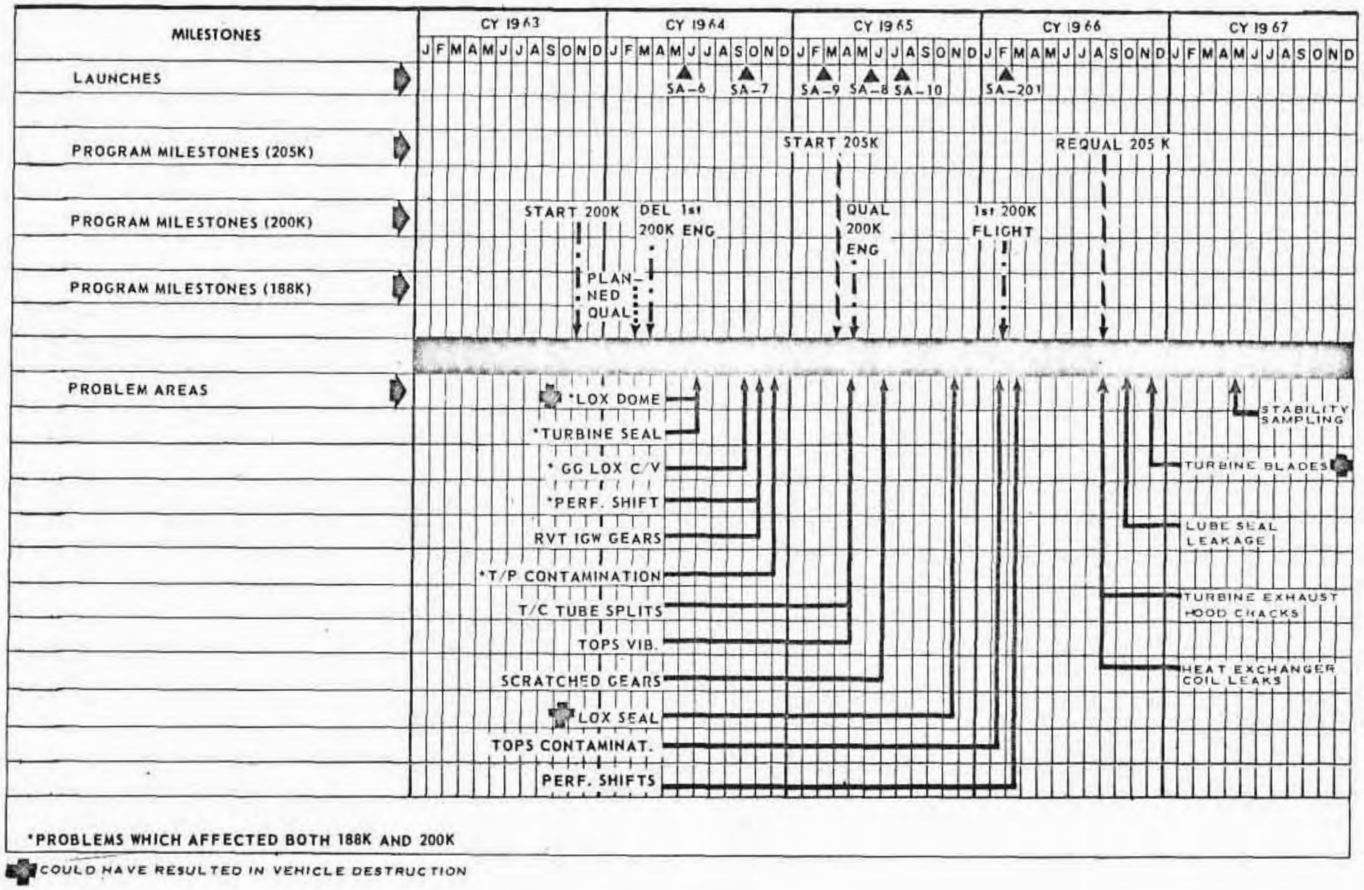


Figure 3

SUSTAINING ENGINEERING
CONCEPT OF OPERATION

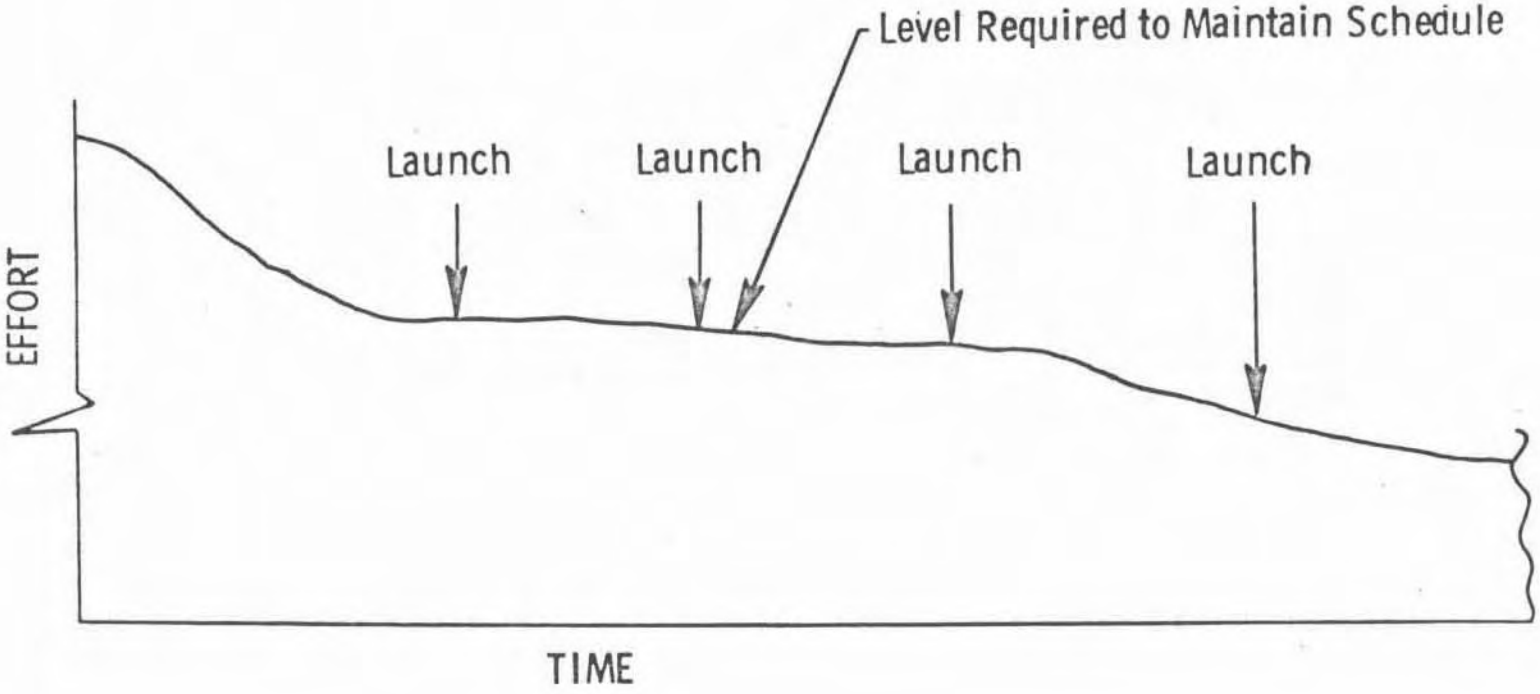


Figure 4

SUSTAINING ENGINEERING
CONCEPT OF OPERATION

Priority 1 - Operational Support

Priority 2 - Reduction in Potential Failure Modes and Operational Restrictions

Priority 3 - Upgrading of the Product

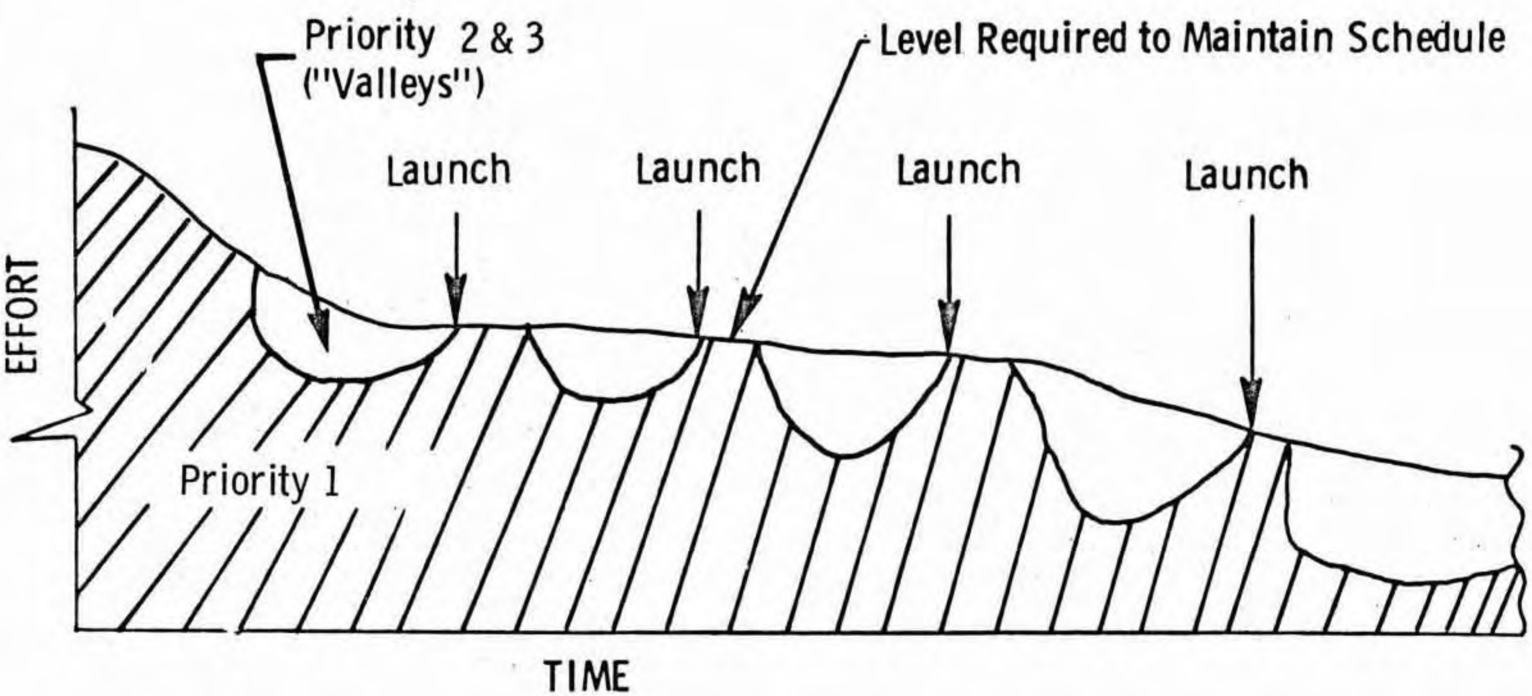


Figure 6

SATURN ENGINE FLIGHT RECORD

ENGINE	NO. FLOWN	ENGINE FAILURES	REMARKS
RL-10	46	0	
H-1	112	1	SA-6 (Engine cut off six seconds early)
F-1	5	0	
J-2	10	0	

20.3-12

Figure

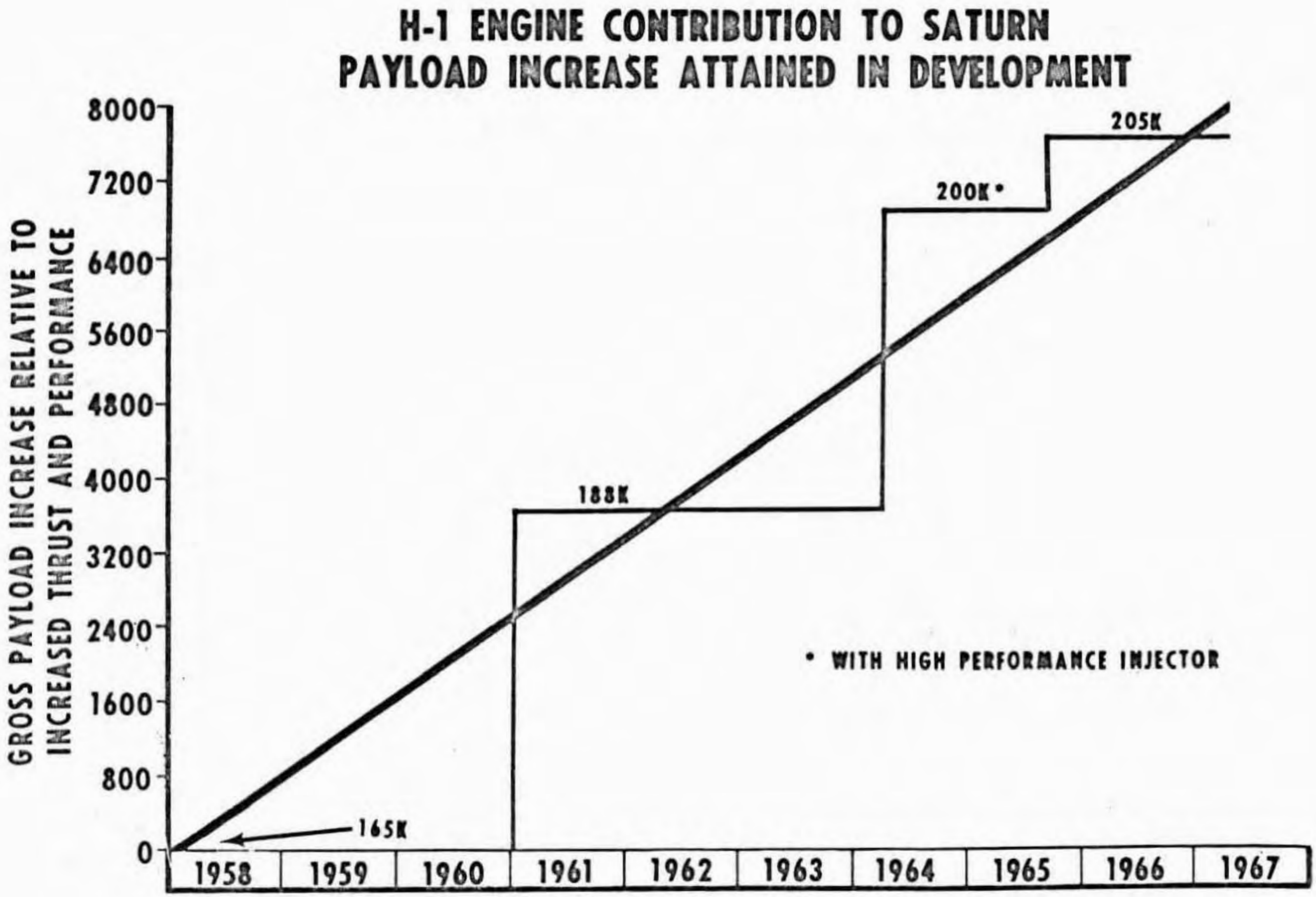

H-1 ENGINE CONTRIBUTION TO SATURN
PAYLOAD INCREASE ATTAINED IN DEVELOPMENT
GROSS PAYLOAD INCREASE RELATIVE TO
INCREASED THRUST AND PERFORMANCE
8000
7200
6400
5600
4800
4000
3200
2400
1600
800
0
165K
188K
200K*
205K
* WITH HIGH PERFORMANCE INJECTOR
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967

Figure 8

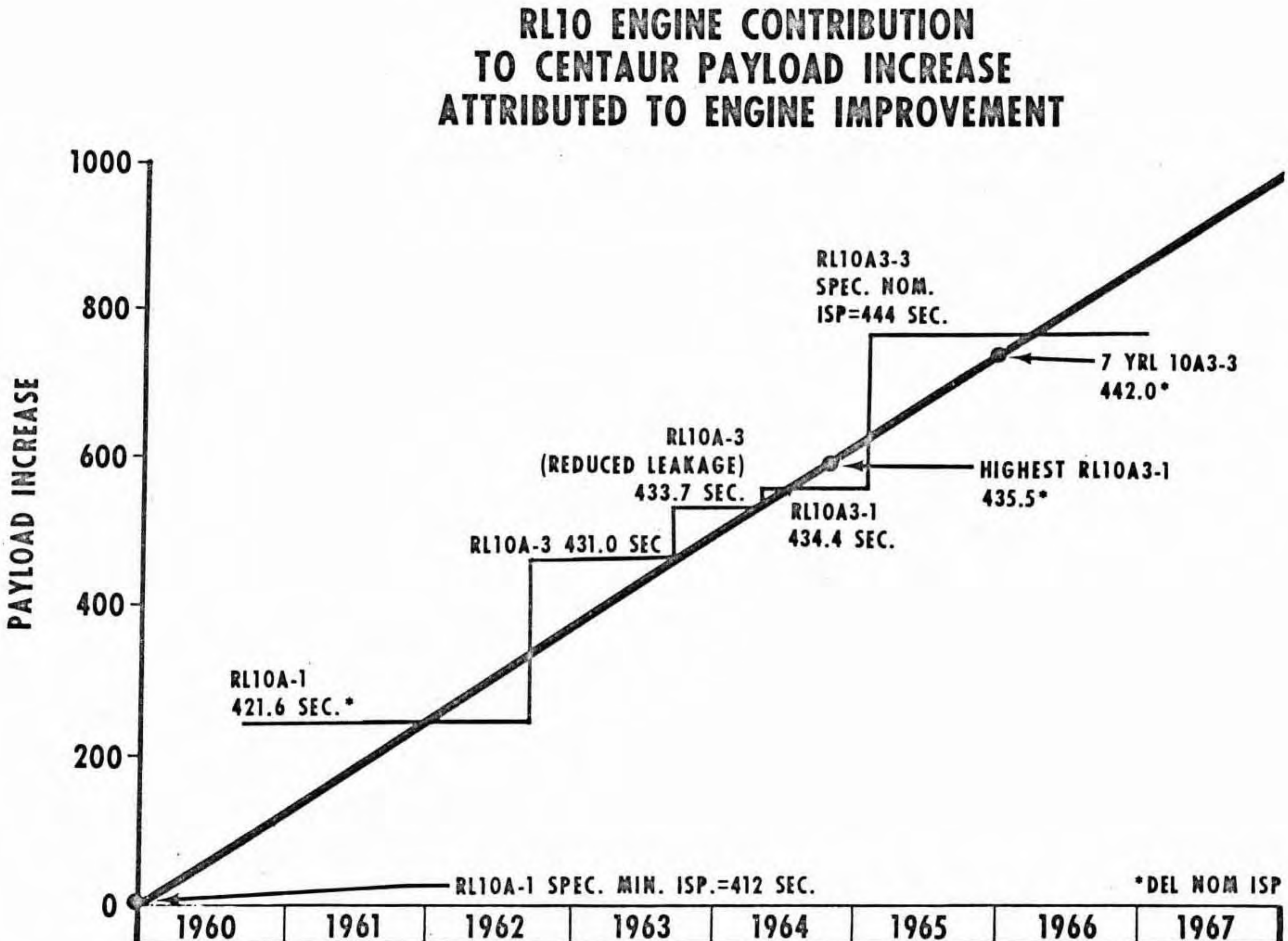
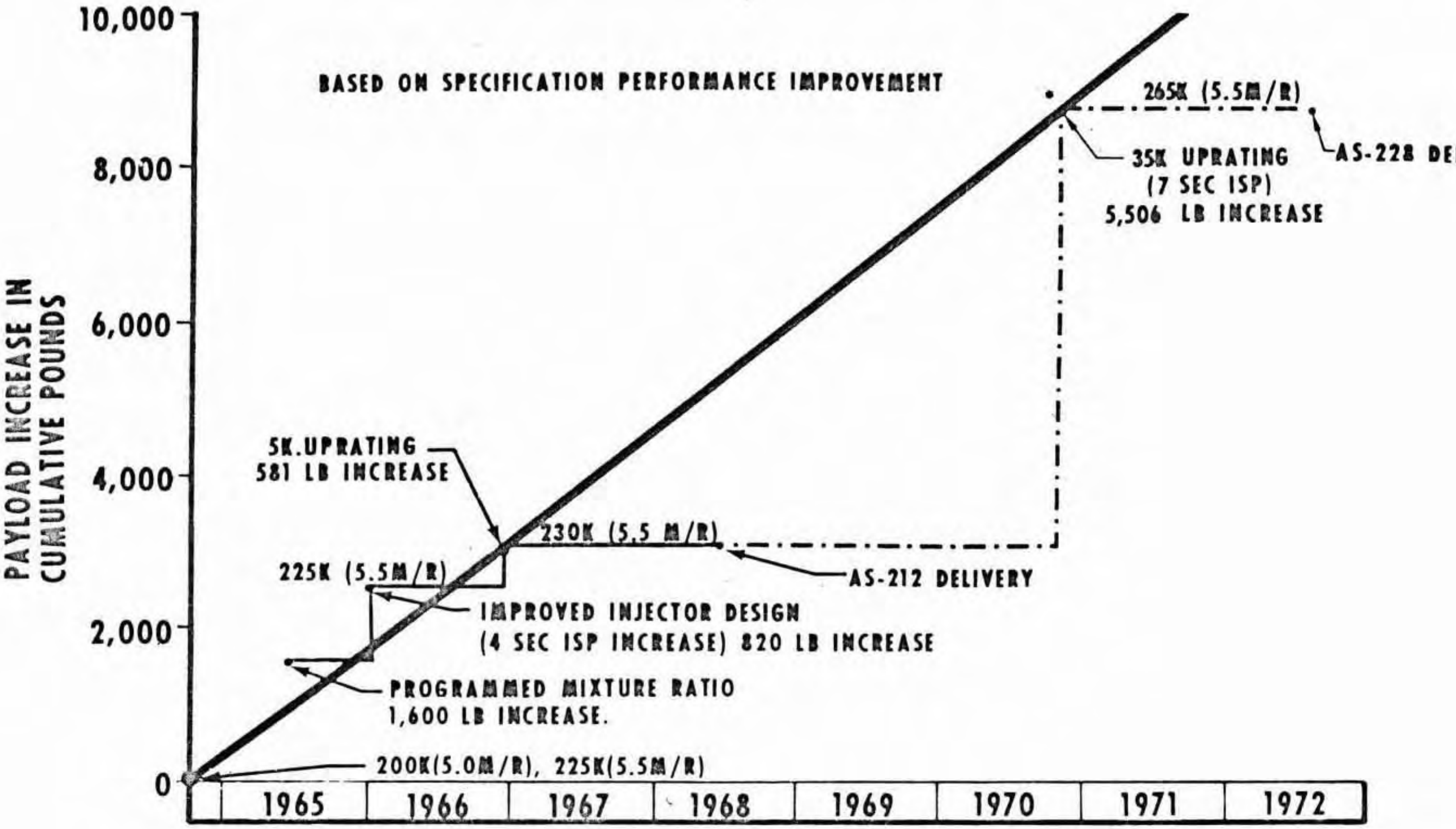

RL10 ENGINE CONTRIBUTION
TO CENTAUR PAYLOAD INCREASE
ATTRIBUTED TO ENGINE IMPROVEMENT
1000
800
600
400
200
0
PAYLOAD INCREASE
RL10A3-3
SPEC. NOM.
ISP=444 SEC.
7 YRL 10A3-3
442.0*
RL10A-3
(REDUCED LEAKAGE)
433.7 SEC.
HIGHEST RL10A3-1
435.5*
RL10A3-1
434.4 SEC.
RL10A-3 431.0 SEC
RL10A-1
421.6 SEC.*
RL10A-1 SPEC. MIN. ISP.=412 SEC.
*DEL NOM ISP
1960
1961
1962
1963
1964
1965
1966
1967
20.3-14

Figure 9

J-2 ENGINE
PAYLOAD INCREASE-UPRATED SATURN 1



*BASED ON DELIVERY OF AS-219 TO CAPE IN OCT 1970 & QUAL OF UPRATED J-2 SIMPLIFIED ENGINE IN JUL 1970

Figure 10

UPRATED F-1 ENGINE
CONFIGURATIONS/SATURN V PAYLOAD INCREASE

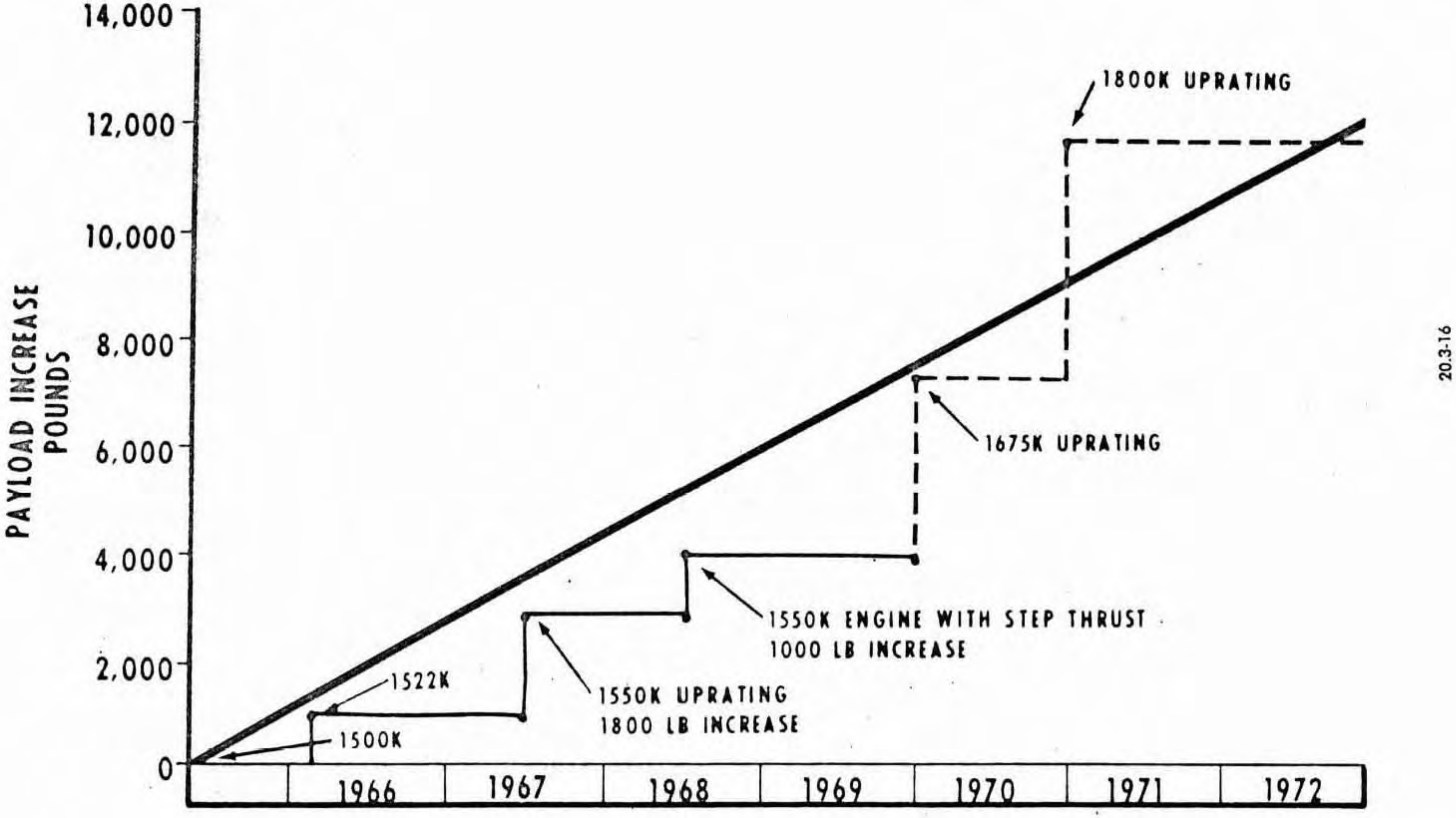
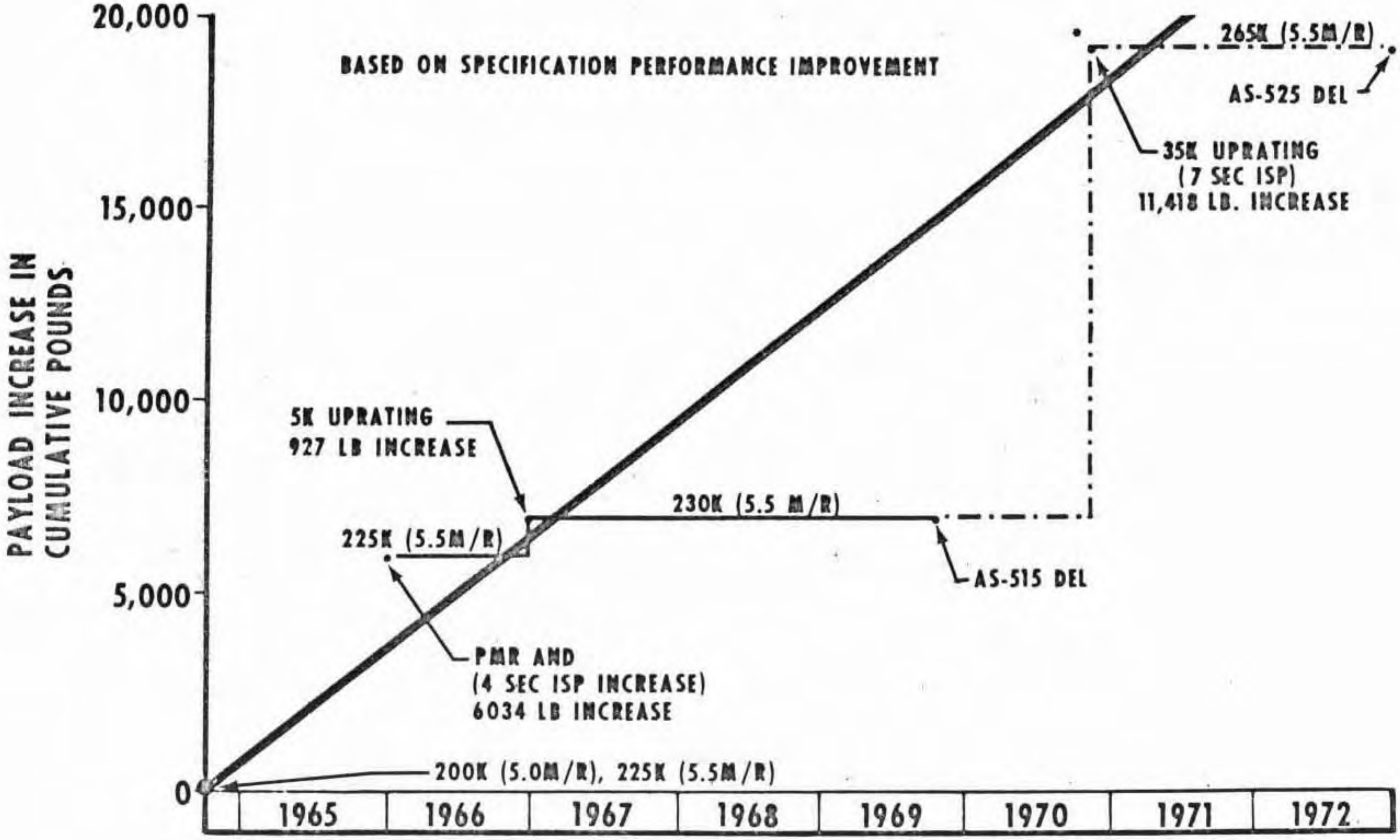


Figure 11

20.3-17

J-2 ENGINE
PAYLOAD INCREASE-SATURN V



*BASED ON DEL OF AS-519 TO CAPE IN FEB 1971 & QUAL OF UPRATED J-2 SIMPLIFIED ENGINE IN JUL 1970.

Figure 12

ENGINE CRITICALITY
SATURN V VEHICLE AS-501

	PERCENTAGE OF TOTAL VEHICLE CRITICALITY ASSESSED TO ENGINES	PERCENTAGE OF TOP TEN MOST CRITICAL ITEMS ASSESSED TO ENGINES
VEHICLE	41.7	64.5
S-IC STAGE	44.7	50.0
S-II STAGE	61.2	65.9
S-IVB STAGE	35.8	52.6

20.3-18

Figure 13