Enclosures:

1) Patent application transmittal letter
2) Method for substantial increase in effective thrust
    - Abstract
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4) 2 Figures - Drawings
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METHOD FOR SUBSTANTIAL INCREASE IN EFFECTIVE THRUST

ABSTRACT OF THE DISCLOSURE

A method comprising the application of thrust in rocket engines and motors in sequential short-pulses to maximize or magnify the effect of the applied forces, by up to 100% in the ideal case; where each pulse is of sufficiently long duration to produce the maximum or desired transient magnification effect, which is also known as the dynamic overshoot; and where the pulses are applied with sufficient frequency to rectify the thrust, or force, near the peak dynamic overshoot value before the magnification effect is lost to other forms of unusable energy, such as, heat.

METHOD FOR SUBSTANTIAL INCREASE IN EFFECTIVE THRUST

TECHNICAL FIELD

The present invention relates to substantial improvement in the performance of rocket engines and motors, and other mechanical systems which use mechanical forces to do mechanical work or produce motion. The invention comprises the application of thrust in a series of short pulses, instead of continuously as has been primarily done before in aeronautics, astronautics and aero-space systems.

DESCRIPTION OF RELATED ART

Payload capabilities of launch vehicles, rockets, missiles and aircraft and the performance of satellites, space probes, and related systems have been limited by the maximum steady-state continuous thrust that can be generated by combustion, and by vehicle design. Simple calculations had shown, from the beginning of the space program in the 1950's, that single-stage-to-orbit launchers are difficult to achieve and, hence, most launch vehicles have been of the multi-stage variety. Staging allows increases in payload capabilities because each stage is discarded after consumption of its propellant, thus reducing the overall weight carried by the rest of the vehicle during flight. While successful, multiple-staging introduces complexities in design and operation, and it is wasteful of the valuable stages that are discarded in each flight. In addition, limitation in payload capability has been a major problem for aero-space and related systems.

Past improvements in performance have been limited by operation at nearly the limit of allowable temperatures, pressures, turbine speeds, etc.; by the availability of alloys, composites, and other materials of greater and greater strength; or by refinement of design using the remarkable improvements in electronic systems, such as, computer hardware and software. But these have provided only incremental improvements.

The primary source of propulsive forces for aerospace systems has been the chemical combustion of liquid or solid propellants. The continuous combustion produces a steady-state thrust, or F, which propels a vehicle and its payload; or does work. But, at start-up, a transient condition exists which magnifies the effect of the applied forces to a theoretical limit of twice the steady-state value, or 2F. During the short transient period, most of the combustion energy is favorably turned into thrust, hence the magnified dynamic overshoot effect 2F. Thereafter, when engines or motors operate in the steady-state continuous mode, parts of the combustion energy are partitioned into unusable forms, such as, strain energy and heat, while only part of the energy is turned into useful thrust, or F.

The steady-state force, F, and the momentary transient force, which can reach 2F, have produced paradoxical situations in the design of aerospace and other systems for a long time. Should rockets and payloads be designed to withstand the steady-state forces, F, or the transient forces, 2F? Systems designed to the steady-state force, or F, tend to be problematic, subject to premature fatigue, failures and accidents due to the momentary overload of the transient forces, which can ideally reach up to 2F, during start-up, throttle-up, throttle-down, or shutdown. On the other hand, systems designed to withstand the maximum transient force, 2F, are wasteful. Here, a system is burdened with considerable structural weight to resist the magnified forces, 2F, for only a fraction of a second, while flying the rest of its mission at the steady-state force value, or F. In this discussion, the safety factors and safety margins apply equally to both cases and do not alter the paradoxical situation.

Designing systems to the steady-state forces, F, and then encountering the transient forces, of up to 2F, in operation can lead to reduction, rather than increase, in payload capability. For example, the Space Shuttle was initially designed in 1972 to carry 65,000 pounds into low earth orbit (LEO), but the payload capability has been reduced to 52,000 pounds by 199[illegible] , showing decline, and not improvement, of capabilities over the years. Using previous methods, a study by the National Aeronautics and Space Administration (NASA) had shown that the Space Shuttle can be made to carry about 250,000 pounds to LEO with 4 solid rocket boosters and four engines, or by burning 6 million pounds of high-energy propellant. By contrast, the present invention can achieve the same performance with less than 2 million pounds of propellant. With the present invention, the very heavy and uncontrolled solid rocket boosters, which weigh more than half of a shuttle's 4.5 million pounds weight, can be eliminated altogether while, at the same time, achieving greater performance. Similar remarkable performance can also be achieved with other systems by using this invention.

The merits, features and advantages of the present invention have not been achieved, fulfilled or imagined by previous methods. The present invention circumvents the dilemma of designing systems to withstand the magnified transient forces, of up to 2F, and not benefiting from these forces, by using the magnified forces throughout, or for a portion of, atmospheric or space flight. The object of this invention achieves unprecedented performance by the method of pulsing-thrust.

SUMMARY OF THE INVENTION

According to the present invention there is provided a method for vast improvement in the payload capability of launch vehicles, missiles, rockets, aircraft and other flying systems that carry payloads in the atmosphere or into, or about, space; and significant weight-savings of these systems and their payloads, including artificial satellites, by means of applying thrust in a series of consecutive-short-pulses, each of sufficient duration to produce the transient dynamic overshoot effect and to rectify the magnified effects at the maximum, or desired, value so as to substantially increase the effective thrust, total impulse, specific impulse, and other performance parameters of liquid propellant, solid propellant, nuclear, ion, plasma and air-breathing rocket engines and motors and other mechanical systems.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing the basic principles of pulsing-thrust operation.

FIG. 2 is a schematic diagram showing one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Refer now to FIG. 1, where in continuous-thrust-operation, the useful thrust is limited to the steady-state value 1. If the thrust is applied very slowly, then its response can only reach to the top of the bars, which represents the steady-state force 1, or F. But, when the thrust of the same magnitude F is applied suddenly for sufficiently long duration, its effect is magnified and the maximum response 2 can ideally reach twice the input force, or 2F. Mathematically, this is the well known response to a unit-step-input force.

FIG. 1 shows the thrust, or force, applied in pulses of short duration, rather than continuously as has been the practice in the operation of engines and motors to date. Each pulse 3, 4, etc. is represented by a bar or a vertical arrow, whose magnitude can be controlled for the desired output. The pulse duration 5 can be controlled to produce the maximum, or desired, magnified effect 2, as described later.

Damping in real systems reduces the magnitude of the dynamic overshoot, but the force magnification can be significant. The maximum magnification can be calculated from the expression: $(1 + e^{-d\ pi/\sqrt{1 - d^2}})$, where, e is the natural logarithm, pi is 3.14159.., and d is the damping ratio for the system under consideration. The damping ratio, d, can be estimated during design or determined by test. For typical launch vehicles, rockets, missiles, satellites, and related systems, the damping ratio, d, is usually less than 0.05 (or, 5%). The maximum dynamic overshoot can be estimated for different values of d from the above expression as shown in Table I below:

TABLE I

Damping ratio	Dynamic Overshoot	Effective Thrust
0.01	96.9%	196.9%
0.05	85.4%	185.4%
0.10	72.9%	172.9%

Most space systems generally have damping ratios of about 0.01 (or, 1%). As seen in the above Table, the effective thrust can be nearly doubled momentarily when the input force is applied suddenly. The thrust magnification effect is the result of that part of the combustion energy that has not yet been converted into other forms, such as, unusable heat which becomes substantial in steady-state operation.

The pulse duration 5 required to reach the maximum dynamic overshoot 2 can be determined by test, or estimated as follows: $1/2f_n\sqrt{1 - d^2}$; where f_n is the natural frequency of oscillation in cycles per second (cps). Typical values for pulse duration required to reach maximum dynamic overshoot are shown in Table II:

TABLE II

Frequency cycles per second	Pulse duration milliseconds
1	500
5	100
10	50

Referring to FIG. 1 again, a given pulse 3 must be of sufficient duration to allow the effective thrust to reach the maximum, or desired, dynamic overshoot value 2, after which the combustion is terminated. During the short pulse period, the combustion product particles flow at high velocity through the nozzle producing propulsive forces, which is the useful part of the combustion energy. Other parts of the total combustion energy are converted into strain, kinetic, vibrational, acoustic, and other forms of energy. If combustion is sustained at the steady-state level 1, as is normally done, then these other parts of energy are lost. By terminating the combustion quickly after the maximum, or desired, dynamic overshoot value is reached, some of the partitioned energy can be recovered as useful thrust. Quick termination of combustion is then intended to return the system to its initial conditions before all of the partitioned energy is converted into unusable forms, particularly, heat.

A system with a natural frequency of 1 cps requires a pulse duration of about 500 milliseconds, or half a second, to reach the maximum dynamic overshoot as seen in Table II. It takes about 500 milliseconds to develop the magnified thrust advantage 2 from one pulse 3. A new pulse 4 will require another 500 milliseconds to reach the next dynamic overshoot 2. The advantage that is developed by the first pulse 3 can be lost during the waiting period 6, i.e., between the termination of pulse 3 and the time that the next pulse 4 builds up to the maximum overshoot. The pulsing-thrust advantage can be realized by rectifying the response near the maximum overshoot value. To achieve this goal, the gap 6 between the two consecutive pulses 3 and 4 must be replenished with another pulse, or pulses. The extra pulse, or pulses, can be developed by additional thruster(s) which allow thruster 3 to return to its initial conditions to produce the magnified effect again, and so on.

This last requirement can be fulfilled in one of several ways. One way is to operate two or more thrusters which can be placed so as to provide symmetric thrust. Four thrusters can be arranged symmetrically and pulsed sequentially, producing 4 single-pulses, say in 500 milliseconds; or in pairs, producing 2 double-pulses in the same period. Alternatively, eight thrusters can be used and pulsed as opposite-pairs to maintain symmetric thrust throughout the pulsed-operation. This configuration also produces 4 double-pulses in a given period. A central thruster, or other combination of thrusters can augment the peripheral thrusters.

The greater the number of thrust-pulses in a given period, the greater is the magnified effect that can be obtained by the rectification process. The rectifying effect of four sequential pulses 3, 7, 8, and 9 is shown in FIG. 2. Using the earlier example of pulse duration of 500 milliseconds, four thrusters can be arranged so that a thrust-pulse occurs every 125 milliseconds, while each thruster is pulsed once every 500 milliseconds. This allows each thruster to be recycled and returned to its initial conditions, while the other thrusters provide the necessary dynamic overshoot to allow rectification at the greater effective-thrust-magnification 10, as shown in FIG. 2. The thrust will be rectified at a lower effective thrust value if the four thrusters are pulsed in pairs, and will be as shown in FIG. 2 for eight thrusters pulsed in symmetric pairs. In general, the greater the number of pulses per unit time, the greater is the thrust magnification; and vice versa.

In the case of solid propellant motors, the pulsing-thrust-magnification can be accomplished by manufacturing or casting the propellant in sections which are isolated from each other and ignited sequentially, or in a programmed combination, by independent igniters or by using heat generated by previously combusted sections in such a manner as to magnify the rectification process as described above.

Since the duration 5 of each pulse is determined by the requirement to generate the maximum, or desired, dynamic overshoot 2, the number of thrusters and pulses per unit time can be chosen to control the frequency of the pulses so as to accommodate other dynamical requirements of the system.

The above principles of pulsing-thrust operation can be applied to liquid bipropellant chemical rockets, liquid monopropellant rockets, solid propellant motors, nuclear rockets, ion propulsion rockets, plasma rockets, and air-breathing boosters. The sequential pulsed-input can be provided by mechanical, electro-mechanical, electromagnetic, or electrical means.

A helpful example to explain the theory of this invention can be found in the electronic circuit, or device, known as the voltage doubler. The voltage doubler is widely used in modern electronic equipment. The voltage doubler, or full-rectifier, doubles the input electric force at the output by clamping and rectifying the input electrical force signal. The rectifying process of the peak mechanical force, or thrust, is analogous to the rectifying process of the peak electrical force, or voltage. Other helpful illustrations can be found in the attached nine figures, from an unpublished paper on the invention. The additional figures show that the method of this invention can be used to eliminate the heavy and uncontrolled solid rocket boosters from the Space Shuttle. It is also shown that 2nd, 3rd, and intermediate stages in other multi-stage vehicles can be eliminated, while allowing greater payload capability. Pulsing-thrust can also give unprecedented weight-saving for satellites, space probes, aircraft, and other systems. The method of this invention gives greater safety and reliability together with the greater performance. This is made possible by the added flexibility to design, or convert existing, systems to operate at lower temperatures, pressures, etc. while delivering greater thrust.

The foregoing description of the example embodiments of the invention has been presented for the purpose of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching.

What I claim is:

1. A method comprising the regulation of thrust in engines and motors to magnify the applied input forces so as to do greater work or to produce greater motion by applying the thrust in short-pulses, each of sufficient duration to produce the transient dynamic overshoot magnification effect, and to rectify the magnified effect at the maximum, or desired, value.

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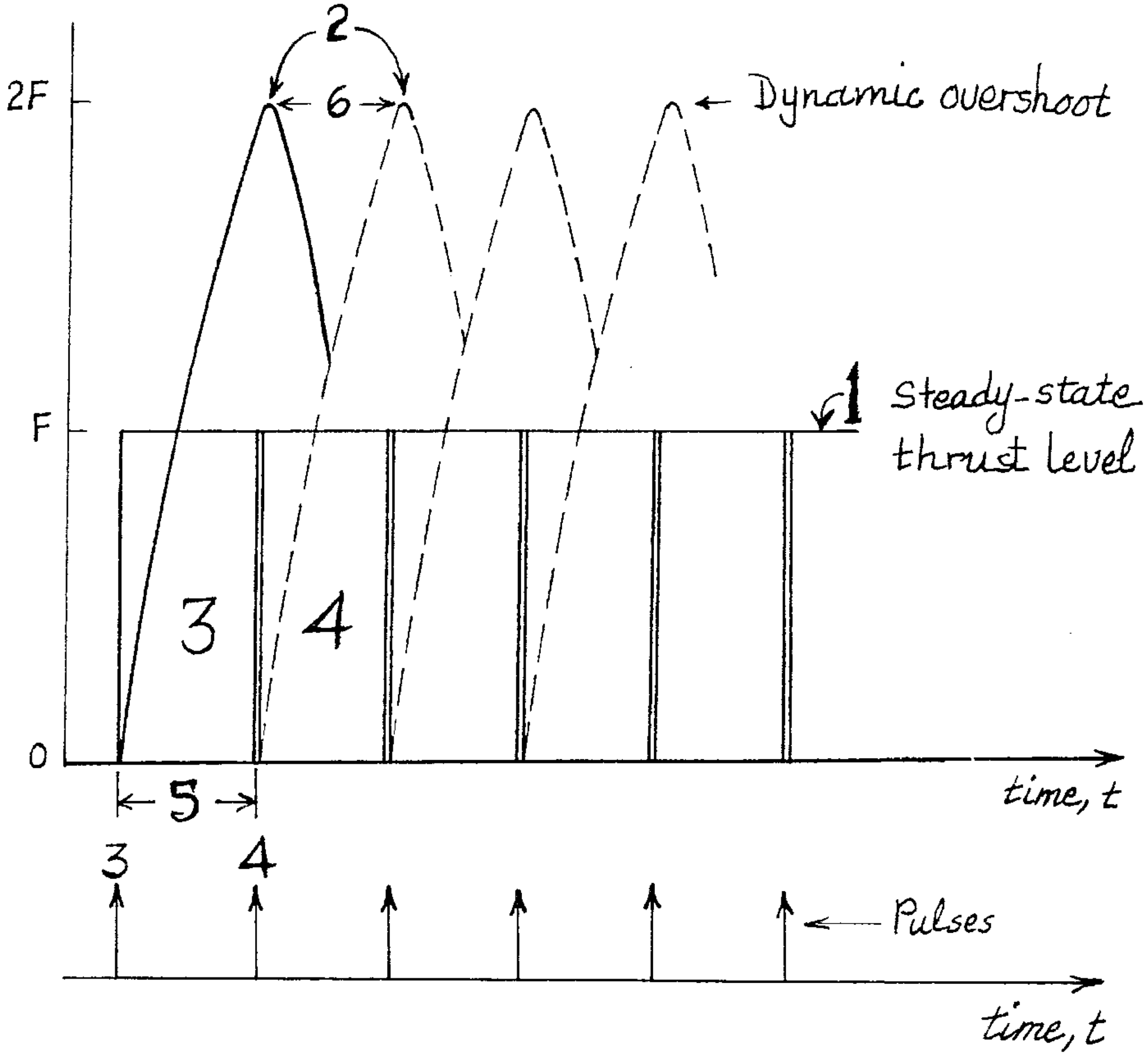

2
2F
6
Dynamic overshoot
F
1
Steady-state thrust level
3
4
0
5
time, t
3
4
Pulses
time, t

FIG. 1

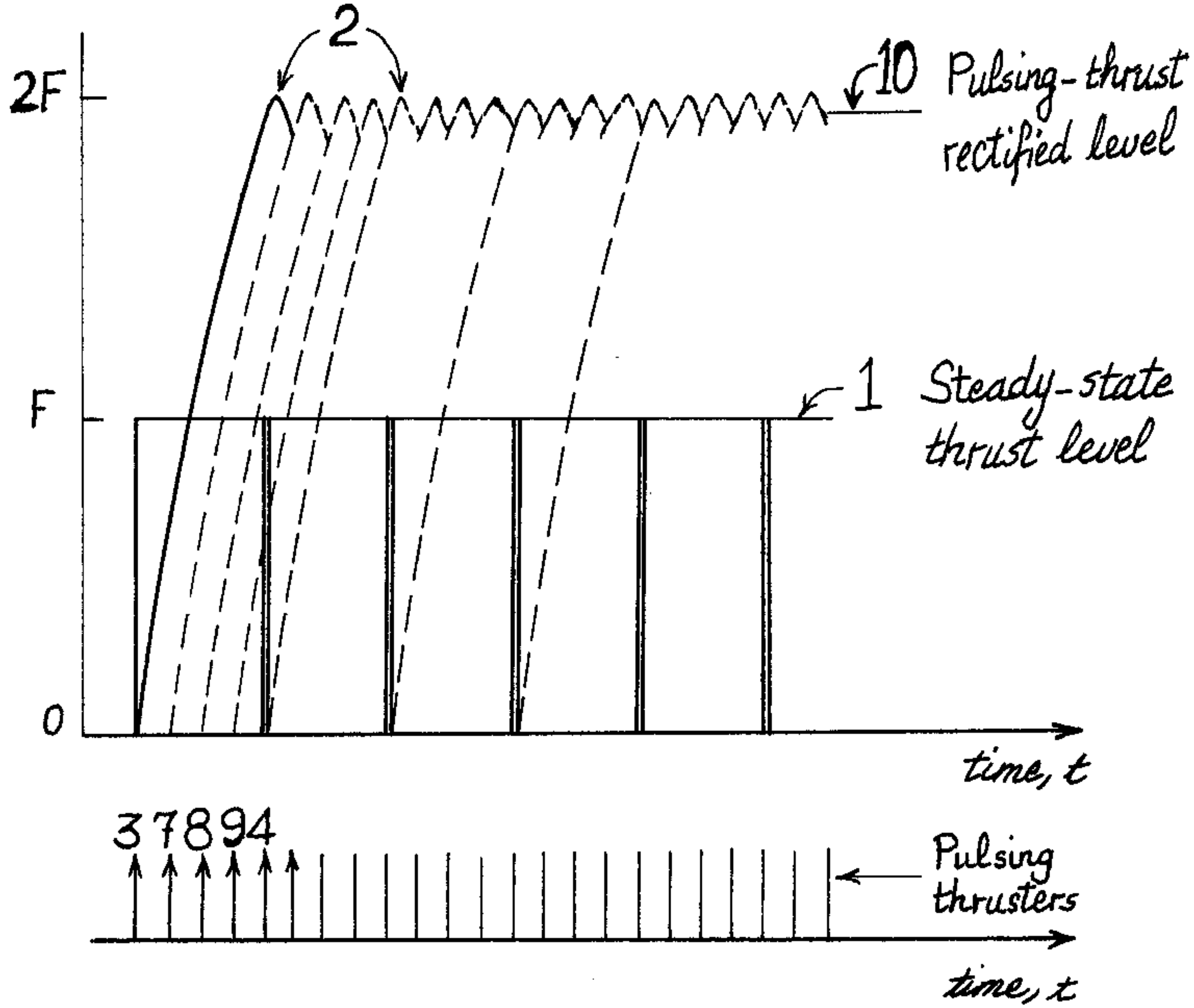

2
10
Pulsing-thrust rectified level
2F
F
1
Steady-state thrust level
0
time, t
3
7
8
9
4
Pulsing thrusters
time, t

FIG. 2

Additional helpful diagrams

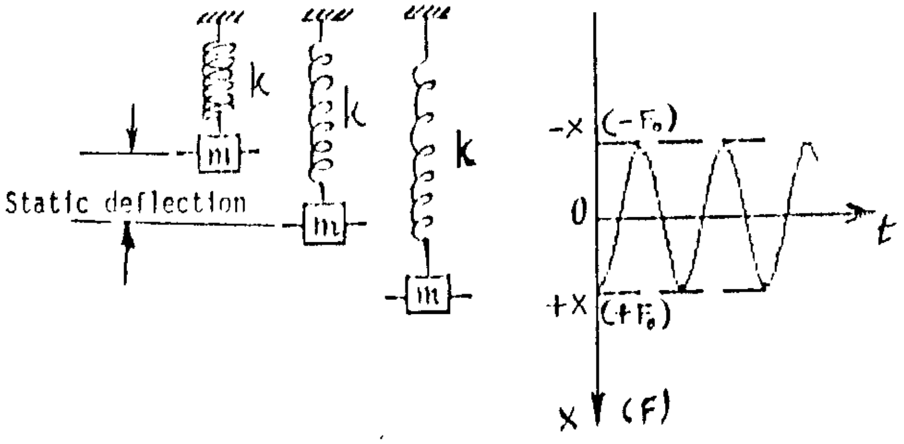


Fig. 1a The common practice of referring oscillations in force fields to the equilibrium position masks the most important feature of oscillations; i.e., the amplitude of the motion, force, etc. (See Fig. 1b).

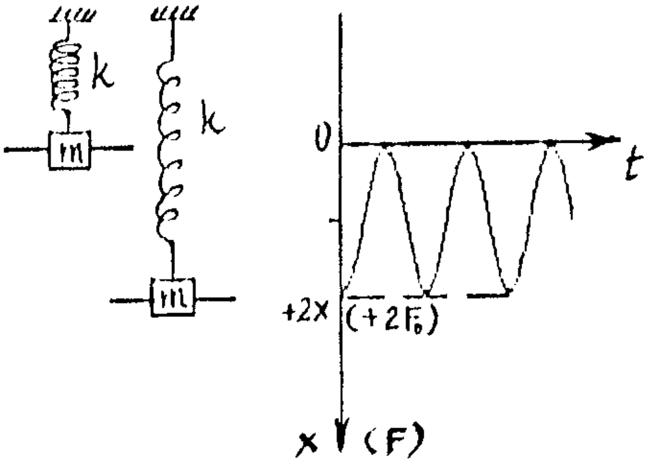


Fig. 1b In force-field-oscillations, motion ranges from 0 to 2x (not from -x to +x); and the force ranges from 0 to $2F_o$ (not from $-F_o$ to $+F_o$).

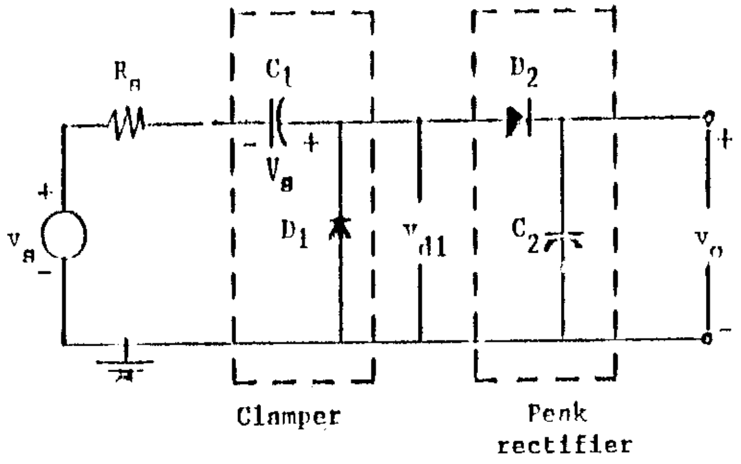


Fig. 2a A voltage doubler circuit doubles the input electric force, or the voltage V_s to $2V_s$, at the output.

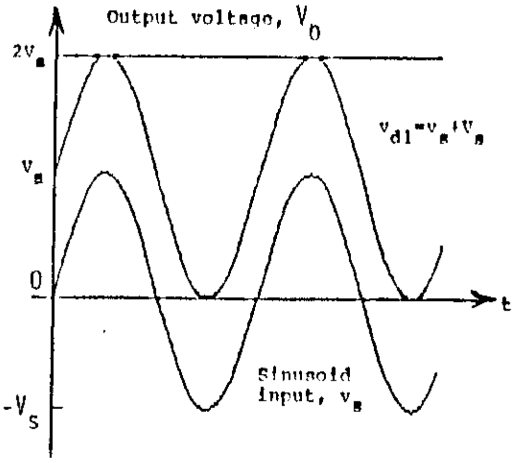


Fig. 2b The voltage doubler utilizes the peak-to-peak electric field force signal. Note that the voltage is not really doubled, but that a process is utilized to benefit from the already naturally doubled signal.

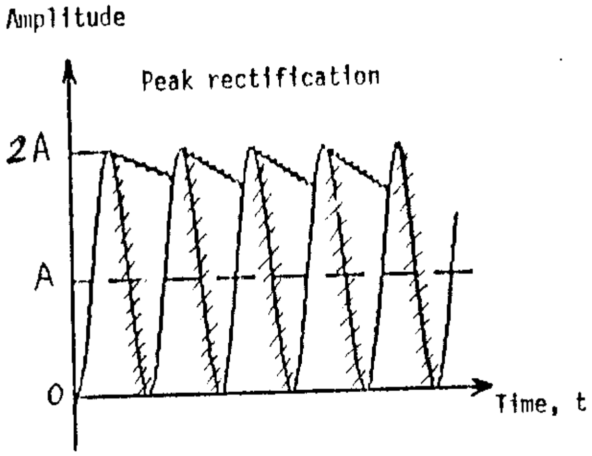


Fig. 2c The shorter the pulses, the smoother is the output of the peak rectifier.

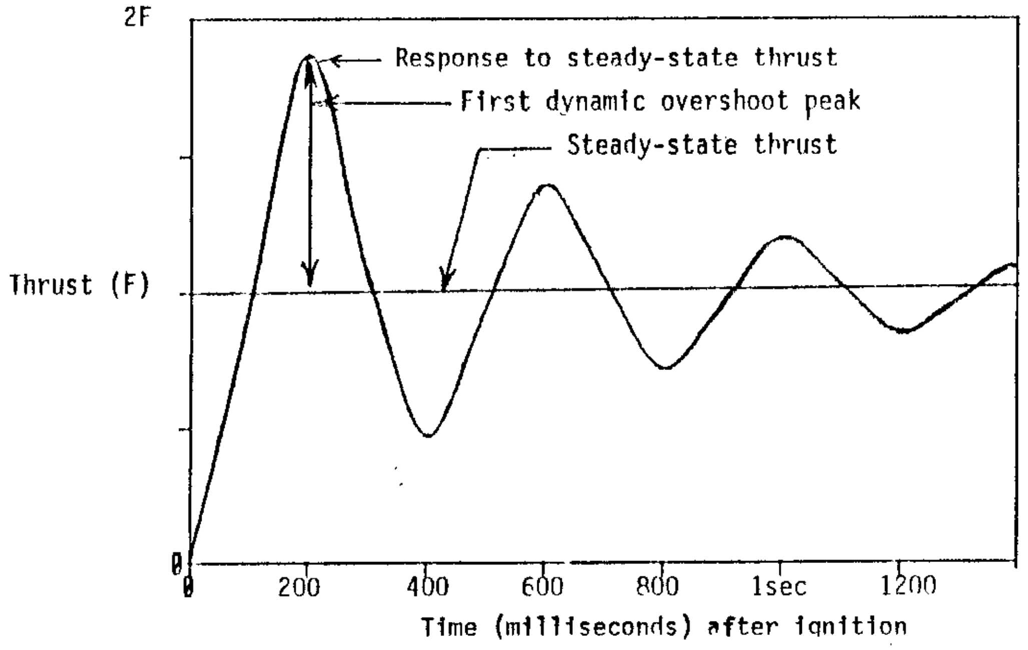


Fig. 3a The rapid surge of thrust of rocket engines and motors causes a transient dynamic overshoot at start-up, or at sudden changes.

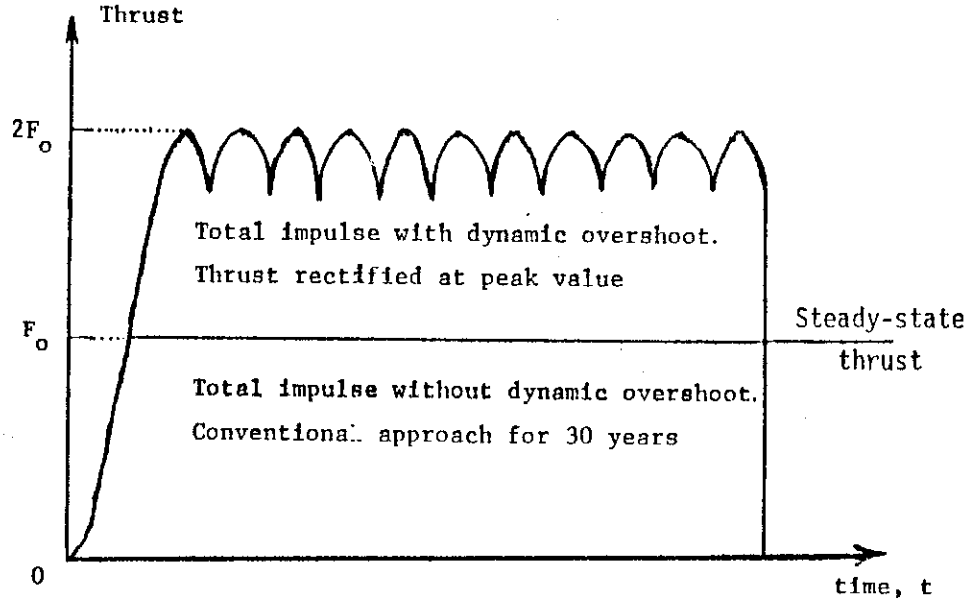


Fig. 3b The effective thrust, or the total impulse, can be nearly doubled by rectifying the response while at the first dynamic overshoot peak.

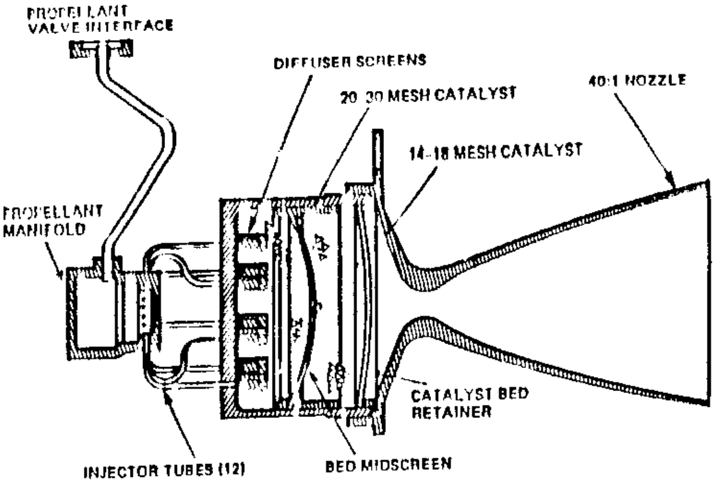
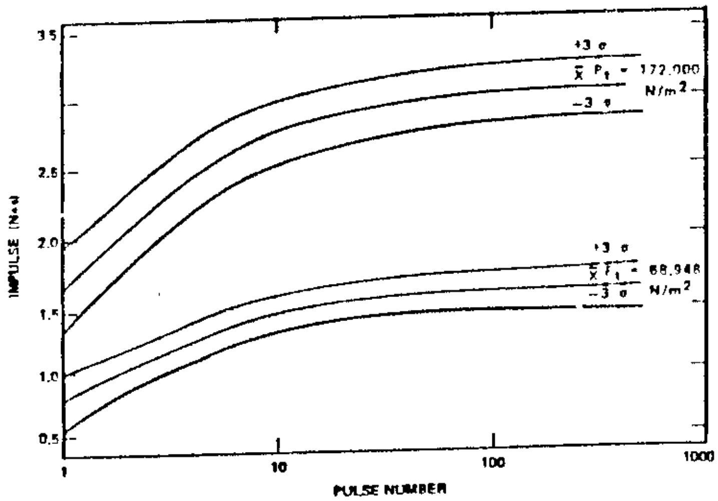


Fig. 4a A typical INTELSAT IV satellite thruster assembly



INTELSAT IV *Thrust, Impulse vs Pulse Number*

Fig. 4b Performance of INTELSAT IV thrusters vs. pulse number.

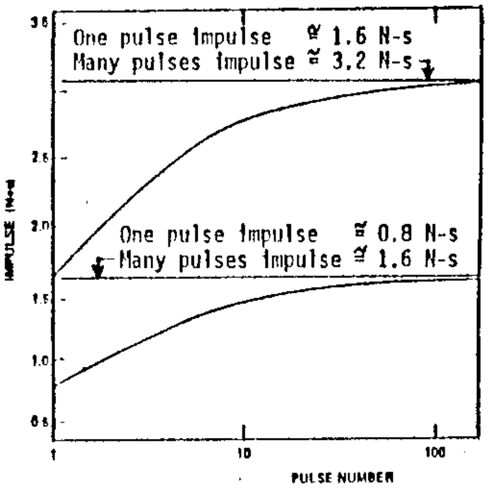
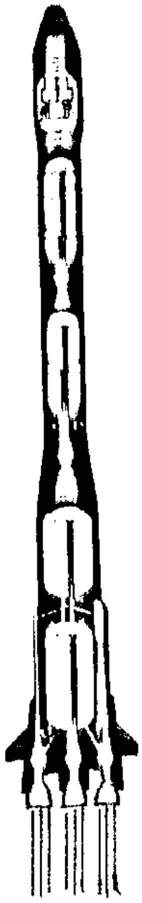


Fig. 4c The impulse is nearly doubled when the thrust pulses are clamped and rectified. Compare with to the voltage doubler.



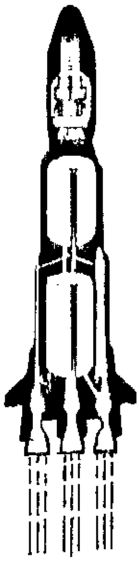
ARIANE characteristics
Lift-off mass 210 tons
Overall vehicle
height 47.3 m

3rd stage (H8):
Mass empty 1,115 kg
Height 9.10 m
Diameter 2.60 m
Propellant LH_2/LO_2
Chamber pressure 35 bar
Thrust 61 kN
Specific pulse 440 seconds
Burn time 560 seconds

2nd stage (L33):
Mass empty 3,109 kg
Height 11.50 m
Diameter 2.60 m
Propellant 34 tons of $UDMH/N_2O_4$
Chamber pressure 53 bar
Thrust 726 kN
Specific pulse 296 seconds
Burn time 133 seconds

1st stage (L140):
Mass empty 13.220 kg
Height 18.40 m
Diameter 3.80 m
Propellant 145 tons of $UDMH/N_2O_4$
Chamber pressure 53 bar
Thrust 2,462 kN (4 engines)
Specific pulse 248 seconds
Burn time 142 seconds

ariane 3



Present configuration

Pulsing 1st Viking-V engines

	N-s	lb-s
I (1st)	350×10^6	78.6×10^6
I (2nd)	97×10^6	21.8×10^6
I (3rd)	34×10^6	7.6×10^6
Total impulse	481×10^6	108×10^6
* Payload	2,600 kg	(5,720 lb)
Velocity ≃	$10,000 \frac{m}{s}$	$(33,000 \frac{ft}{s})$

Impulse $\simeq 700 \times 10^6$ N-s
Propellant $=$ 145,000 kg
Structure $\leq$ 13,000 kg
*Payload $=$ 5,000 kg

Total mass $\simeq$ 163,000 kg
Mass Ratio $= \frac{163,000}{18,000} = 9$
$I_{sp} \simeq$ 438 seconds
Velocity $\geqslant 10,000 \frac{m}{s} \left(33,000 \frac{ft}{s}\right)$

Fig. 5 The Ariane-3 1st-stage alone can carry greater payload with pulsing-engines.

SPACE SHUTTLE SYSTEM

OVERALL LENGTH	184.2 FT (56.1 m)
HEIGHT	76.6 FT (23.3 m)
SYSTEM WEIGHT	
– DUE EAST	4 490 800 LB (2037 Mg)
– 104°	4 449 000 LB (2018 Mg)
PAYLOAD WEIGHT	
– DUE EAST	65 000 LB (29 483 kg)
– 104°	32 000 LB (14 515 kg)

EXTERNAL TANK

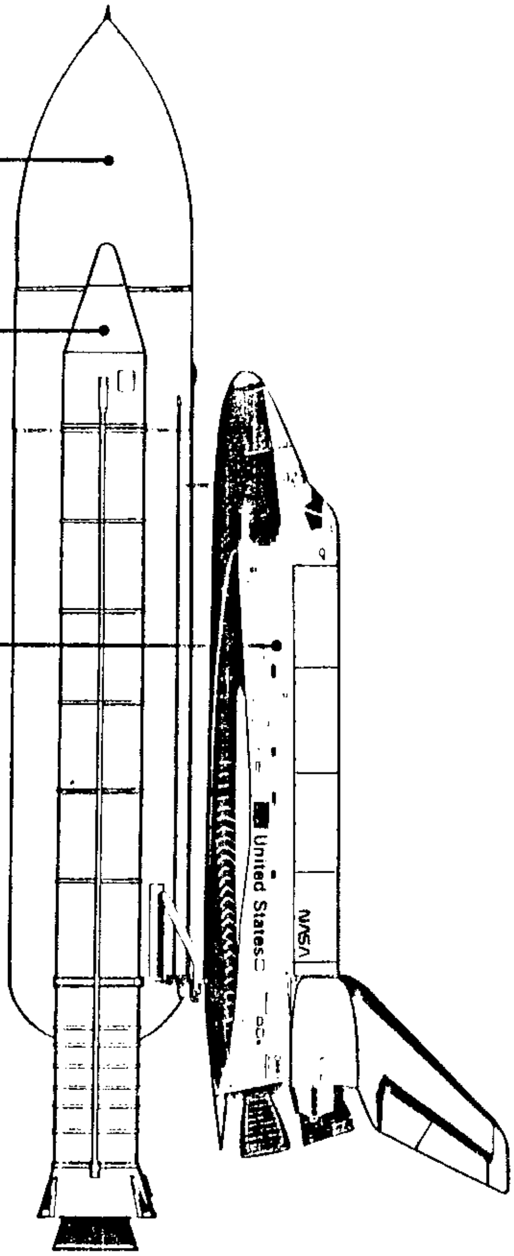
DIAMETER	27.8 FT (8.5 m)
LENGTH	154.4 FT (47.1 m)
WEIGHT	
– LAUNCH	1 649 600 LB (748 242 kg)
– INERT	71 000 LB (32 205 kg)

SOLID ROCKET BOOSTER

DIAMETER	12.2 FT (3.7 m)
HEIGHT	149.1 FT (45.4 m)
WEIGHT (EACH)	
– LAUNCH	1 292 600 LB (586 310 kg)
– INERT	183 800 LB (83 370 kg)
THRUST (EACH)	
– LAUNCH	2 700 000 LB (12 010 140 N)
SEPARATION MOTORS (EACH SRB)	
– 4 AFT 4 FORWARD	
– THRUST (EACH)	22 000 LB (97 860 N)

ORBITER

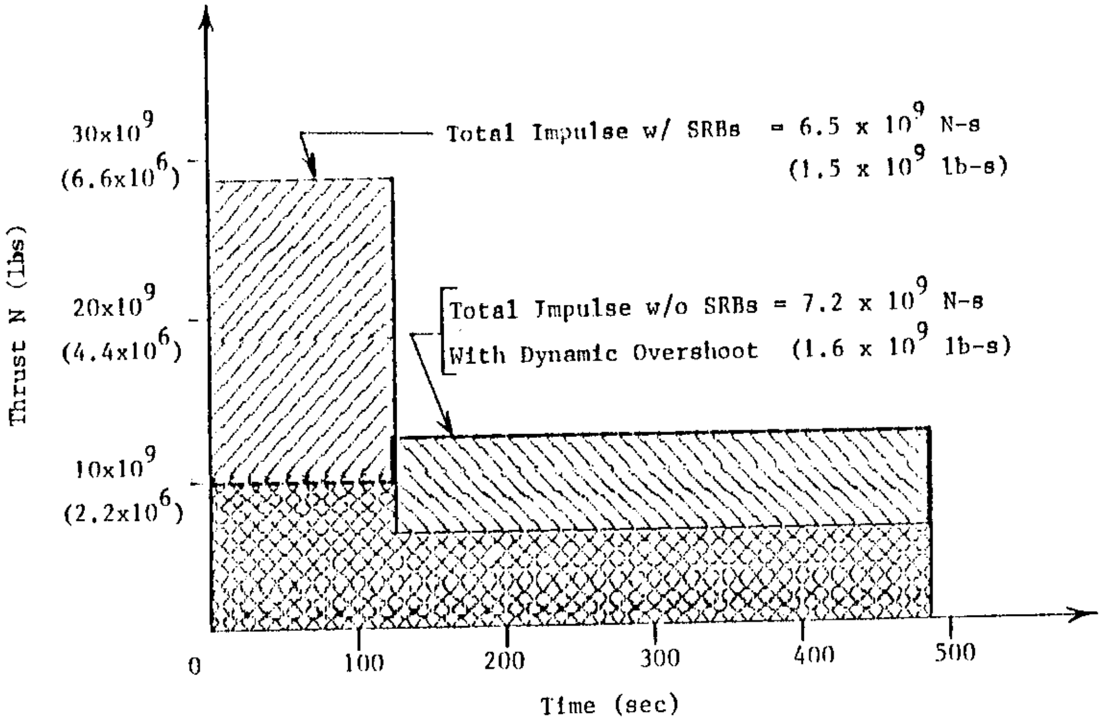
LENGTH	122.2 FT (37.2 m)
WINGSPAN	78.1 FT (23.8 m)
TAXI HEIGHT	~57 FT (~17 m)
PAYLOAD BAY	15 FT DIAM BY 60 FT LONG (4.6 m BY 18.3 m)
CROSS RANGE	1100 N. MI. (2037 km)
MAIN ENGINES (3)	
– VACUUM THRUST EACH	470 000 LB (2090.7 kN)
OMS ENGINES (2)	
– VACUUM THRUST EACH	6000 LB (26.7 kN)
RCS	
– 38 ENGINES	
VACUUM THRUST EACH	870 LB (3869.9 N)
– 6 VERNIER ENGINES	
VACUUM THRUST EACH	25 LB (111.2 N)
WEIGHT	
– INERT	162 000 LB (73 482 kg)
– LANDING	
WITH PAYLOAD	~211 000 LB (95 707 kg)
WITHOUT PAYLOAD	~179 000 LB (81 193 kg)



Space Shuttle system.

(Source: Reference 12)

Fig. 6



Space Shuttle performance comparison: Pulsing-SSMEs vs. steady-state-SRBs-SSMEs

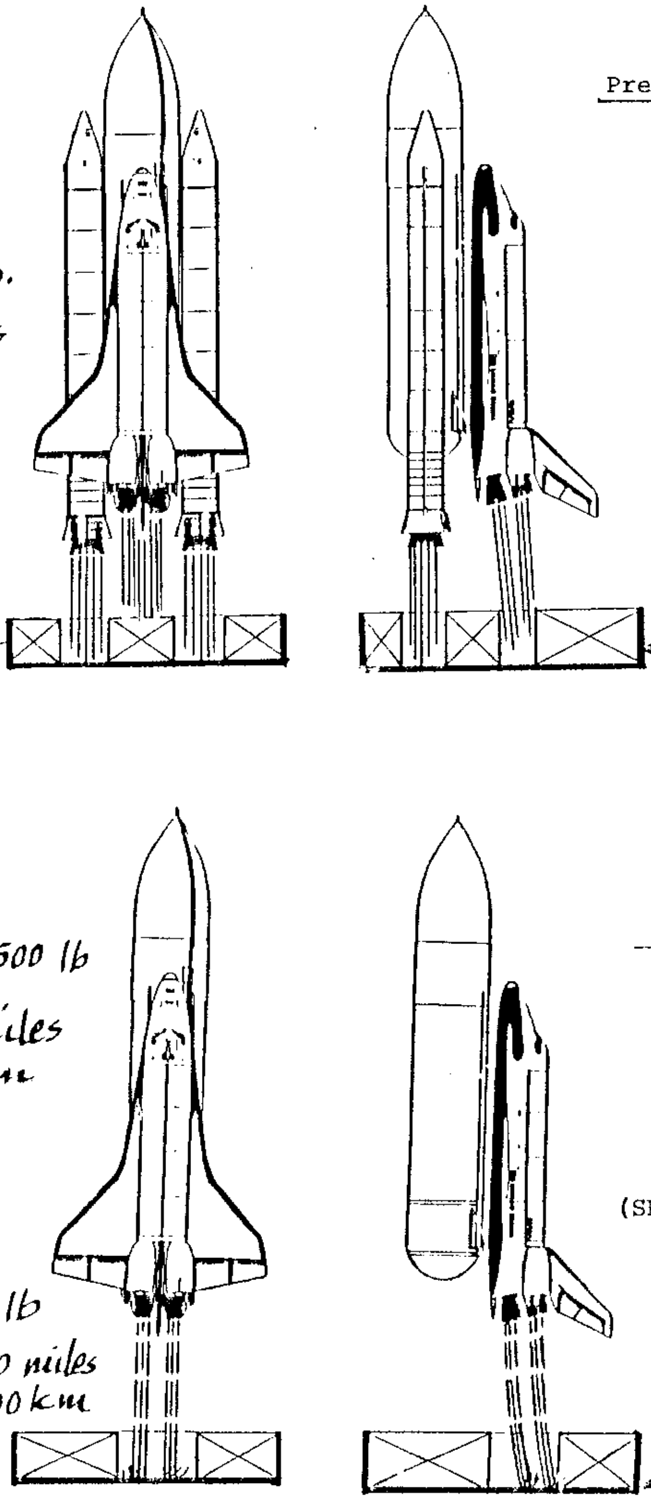
Orbit Advantage		
ET Propellant		1,578,600 lbm
ET Structure		71,000 lbm
Orbiter + Payload		211,000 lbm
Total at liftoff		1,860,600 lbm
Mass at end-of-burn		282,000 lbm
Mass Ratio (MR)	≃	6.6
Pulsing-SSME I_{sp}	≃	800 seconds
Attainable velocity	>	12,000 m/s 39,600 ft/s

Orbiter + ET + Payload all reach GTO, or geostationary transfer orbit height of, 36,000 km (22,500 miles)

Payload Advantage		
Velocity	≃	25,000 ft/s
LEO	≃	125 miles
I_{sp}	≃	800 seconds
MR	≤	4
Mass to Orbit		482,500 lbm
ET Structure		71,000 lbm
Orbiter + Payload		411,500 lbm
Orbiter		179,000 lbm
Payload	≥	232,500 lb

Placed in low earth orbit (LEO) 100 - 300 miles.

Fig. 7 Pulsing-SSMEs alone can generate a comparable impulse and greater performance than the combined SRBs-SSMEs steady-state thrust.



Only LEO operation

Payload < 50,000 lb.

Orbit ~ 125 miles
200 km

Present configuration

Liftoff weight

2,037,000 kg

4,490,000 lb

Total impulse

6.5×10^9 N-s

1.5×10^9 lb-s

LEO operation

payload > 232,500 lb

Orbit ~ 125 miles
200 km

GTO operation

payload > 65,000 lb

Orbit apogee ~ 22,500 miles
36,000 km

Dynamic overshoot configuration

Liftoff weight

843,949 kg

1,860,600 lb

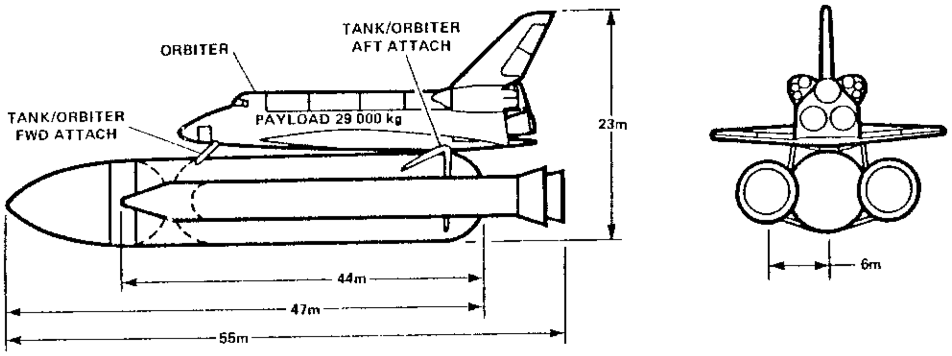
(SRBs eliminated altogether)

Total impulse

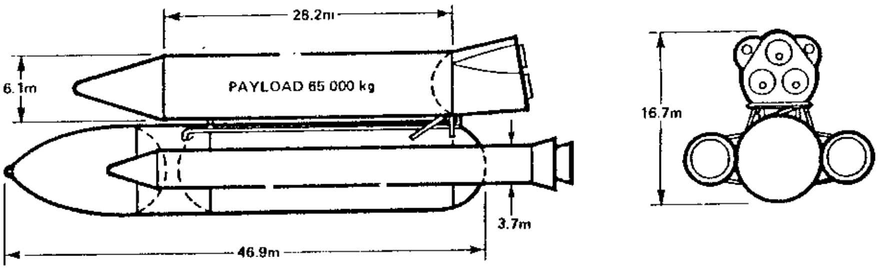
7.2×10^9 N-s

1.6×10^9 lb-s

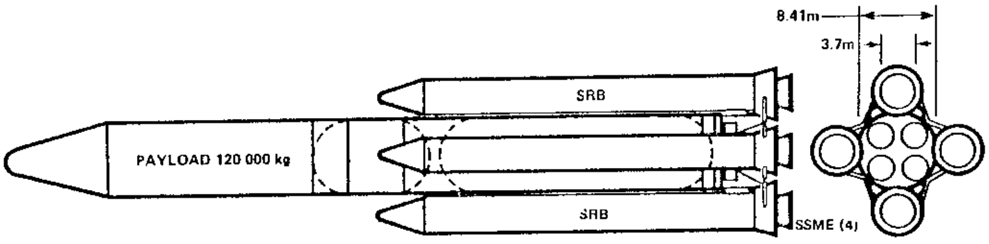
Fig. 8 Pulsing-SSMEs Shuttle can carry more payload than the massive Energia and it can easily reach Geostationary Transfer Orbit (GTO) with its payload and External Tank.



SPACE SHUTTLE VEHICLE



2 SRB SHUTTLE DERIVATIVE



4-SRB SHUTTLE HLLV DERIVATIVE –
BASELINE LIFT VEHICLE

Fig. 9 A NASA study shows that it takes 4-SRBs and 4-SSMEs (or about 7 million pounds assembly) to launch 120,000 kg (264,000 lb) on a Shuttle derivative. A similar payload can be launched with only 3-pulsing-SSMEs and NO SRBs (or only about 2 million pounds assembly)!

(Figure source: Reference 13).