

Overview of Spacecraft Drive Systems

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A work of fiction, meant for adults. Read something else if you are not an adult, or are offended by stories with sexual content. Then again, if all you're looking for is in-out, in-out, in-out, you should probably read something else. I welcome constructive comments. Enjoy.

This article presents a non-technical overview of major spacecraft drive systems. The amount of mathematics and physics has deliberately been kept to a minimum. Standard treatises are available for those wishing to explore subtopics in detail. Links to related non-technical articles are shown in **bold**. Links to related technical articles are shown in ***bold-italic***. Drive systems are presented in their order of development.

This development is presented from an Earth-centric point of view, and accepting the hypothesis that there was a First Age of Space predating what we on Earth know as our recorded history.

Reaction Drives

Reaction drives, or thrust drives, are thought to be the first drive systems developed by Earth-bound Man. They involve the basic physics principal of equal and opposite reaction (see ***Newton, Isaac***). An example is a child releasing an inflated balloon. The air escaping through the constricted neck of the balloon imparts thrust on the balloon.

Reaction drives differ mainly in the method used to propel material away from the object to be moved. In the first developed, chemical reactions between fuel components produce reaction products, usually gasses, at high temperatures and velocities. These gasses are directed through the nozzle to produce thrust. An energy source such as nuclear or thermonuclear reaction may be used to heat fuel, the heated fuel being expelled through a nozzle to produce thrust. Electric or electromagnetic fields may be used to accelerate fuel ions or atoms, providing thrust.

Chemical reactions are capable of producing very high thrust but consume prodigious quantities of fuel. Primitive chemical fuels included liquid hydrogen and liquid oxygen. Chemical thrusters were commonly used to lift vehicles and their payloads from the surface of the planet. At the other extreme, electric/electromagnetic thrusters (see ***VASIMR***) were very efficient, but produce low thrust (see also ***specific impulse***). They were used to propel the first man-made vehicles out of the Earth system.

Light Sails -- the Sail Ships

While these are a form of reaction drives, they merit their own category. They operate by harnessing the very slight pressure of light, and the particles emitted by a star. While the specific impulse is very slight, it is also a very efficient system, and requires no on-board fuel for main propulsion.

These systems reach their pinnacle in the great Sail Ships, or pod ships, which sailed between the stars. With sails hundreds of kilometers or more across, they represented the romantic height of man's reach to the Stars.

Sail Ships were used in the Second and Third Ages of space, and evidence points to their use in the First Age of Space as well (see **Space Travel, History Of, and Diaspora**).

Sail Ships of necessity were built in far orbit, away from debris which could contaminate or puncture a sail. The ship consisted of the sail and a string of pods. The sail was attached to the control pod, which held the single crew member. Steering was accomplished by shortening or lengthening control lines from the control pod to the sail.

Clusters of cargo pods were attached to the control pod. Passengers, in suspended animation and sealed in pods, were also attached in clusters to the control pod. Hundreds of pod clusters made up a ship.

While a Sail Ship could be launched on solar pressure alone, large lasers were also used. Eventually a set of eight massive **launch lasers** orbiting Earth were used to launch sail ships on their long, slow, one-way journeys to the stars.

The single pilot watched over the centuries-long journey. A combination of suspended animation techniques allowed the pilot's sense of time to be slowed down greatly, as was the pilot's metabolism, greatly reducing the need for nutrition and oxygen. The pilot would "awaken" periodically for what seemed to be minutes and were actually months, check the status of automated systems, perform the necessary corrections, and return to sleep.

In the Second Age of Space, it is estimated that fewer than fifty sail ships were launched over two and a half centuries until they were replaced by Lawson Ships. Looking back on the records of those first efforts, one cannot help but feel the romance and hope of the time. For what else other than hope would urge a man to Captain a Ship on a century-long voyage into the unknown?

But that hope succeeded, at least for a time. Man of the early Second Age of Space discovered and colonized new worlds using the great Sail Ships. Bonus was settled by an early Sail Ship. Settlements were also established on Gibson's World, Hoodah, Penticost, Ruch, Persephone, Galdriel, Moss, and Kaladra. Sail ships reached a number of other star systems, not finding habitable planets. While some still argue that Almost was settled by a Sail Ship in the Second Age of Space, the inhabitants of Almost disagree, giving more credence to the existence of a First Age of Space, and perhaps to colonization from another world other than Earth.

Lawson Drive

Developed by **Felix Lawson**, the Lawson Drive is commonly referred to as “horrific,” and represents the culmination of the Second Age of Space.

It was well known that the maximum velocity of an object in normal space is limited, even given unlimited fuel. *Relativistic mechanics* (see **Einstein, Albert**) says that as the velocity of an object approaches the speed of light, its effective mass increases. This means more and more energy must be expended to increase the velocity of an object, and also means that the velocity of light cannot be equaled or exceeded by an object with nonzero mass, for as an object approaches the speed of light, its mass approaches infinity, as does the amount of thrust required to accelerate it.

Lawson discovered an effect (*Lawson Effect, or Lawson Swindle*) which has a side effect of temporarily displacing mass. The effect is velocity dependent, increasing with velocity. Combined with a reaction drive such as the **Bussard Ram**, the Lawson Drive produces greater acceleration from the same amount of thrust, as the effective mass being accelerated seems less. The ratio of mass displaced by the effect to the rest mass approaches 1 as the velocity approaches 0.7071 times the speed of light.

From this description, the Lawson Drive would seem to be quite a promising proposition. And indeed it was used for almost two hundred years at the end of the Second Age of Space.

The realities give it the appellation “horrific.”

The Lawson Effect requires prodigious amounts of power. As stated earlier, the temporary displacement of mass is a secondary effect. The primary effect is the generation of vast amounts of radiation, radiation inimical to life. The amount of radiation from an operating Lawson Drive increases as its velocity increases. Indeed, near its terminal velocity, the last of the Lawson Drive ships obtained an appreciable amount of thrust from Lawson radiation.

The Lawson Effect requires so much power, especially at lower velocities, that the only practical means of powering it is through *thermonuclear fusion*. The fusion source is also used to provide thrust.

The theoretical basis for thermonuclear fusion powered vessels fueled by interstellar hydrogen was worked out by **Bussard et al.**, and is a type of reaction drive. The **Bussard Ram** was not efficient enough on its own to be practical. The addition of the Lawson Effect produced a new drive system with performance so different from the standard Bussard design that it is called the Lawson Drive.

Lawson ships are squat, hollow cylinders. The forward edge of the cylinder contains superconducting electromagnetic coils used to produce magnetic fields which scoop interstellar hydrogen fuel into the center of the cylinder. The hollow center of the cylinder contains the thermonuclear fusion source. The central body of the cylinder holds superconducting field coils

for containing the fusion reaction, and for extracting power from it. The rear of the cylinder contains the Lawson Effect generators.

The body of the cylinder also contains crew, cargo, and fuel storage. Liquid hydrogen is the usual fuel, with important variations being isotopes of hydrogen, deuterium and tritium. Liquid hydrogen is very cold, and was used to cool the superconducting magnetic coils forming the containment and scoop fields as well as a fuel source.

Starting a Lawson Drive

Starting a Lawson Drive was an exciting and risky proposition. The ship was accelerated using chemical thrusters, then commonly discarded. Fuel (hydrogen) was injected into the front of the cylinder, and the thermonuclear reaction ignited. The large amount of energy released by the thermonuclear fusion reaction was in part converted to electricity to power the containment fields for the thermonuclear reaction, the scoop fields, and the Lawson Effect. Remaining fusion products, at high temperatures and velocities, exit the rear of the cylinder producing thrust.

This sounds simple. The technology of the Lawson Drive is also notable for the seemingly innocuous terms used to describe spectacular (and devastating) failure modes.

Where the original Bussard design could make use of a small fusion source, using techniques such as ***inertial confinement*** or ***laser ignition***, the Lawson system requires orders of magnitude more energy. The fusion reaction is ignited in the center of the cylinder by detonating a (relatively) small thermonuclear bomb (see **Teller, Edwin; Kurchatov, Igor Vasilievich**). If fuel flow is insufficient to bring up power to the containment fields quickly enough, the drive “fizzles,” and the ship is destroyed by the thermonuclear explosion.

If the fuel flow is too rich, the fusion reaction grows outside the containment fields, and the drive “blooms.” The fusion reaction breaches the inner hull of the cylinder, releasing large quantities of liquid hydrogen fuel into the fusion reaction. The ship is engulfed in a very large thermonuclear explosion.

If startup is successful, the ship accelerates quickly, reaching accelerations of 0.2 to 30 times the force of gravity in a fraction of a second. Once the scoop fields begin funneling interstellar hydrogen to the fusion source, fuel flow from on-board sources may be reduced.

In the first decade of the Lawson Drive, about a third of ships launched experienced startup failures such as fizzles or blooms. Lawson Ships were not launched in the vicinity of planets or inhabited structures.

Operating the Lawson Drive

The excitement was not over once the drive started successfully. Drive operation had to be continuously and meticulously controlled to avoid fizzles or blooms, which could be caused by unexpected changes in the density of the surrounding interstellar medium. Too little fuel and

containment fails. Too much fuel and the fusion reaction cannot be contained. Asteroid fields and fields of dark matter were to be avoided.

If the drive operated nominally, continuous acceleration at one standard gravity resulted in a velocity of one tenth the speed of light (0.1c) in approximately 20 days. At an acceleration of five gravities, 0.1c was reached in less than four days. At that point, the Lawson Effect became increasingly significant, with terminal velocity of approximately 70% of the speed of light (0.7071c) being reached in approximately the same amount of time it took to reach 0.1c.

Terminal Velocity

0.7071c is referred to as the terminal velocity of the Lawson Drive for a very good reason. Recall that the Lawson Effect becomes more and more efficient as the velocity increases. Unless thrust is throttled back, the acceleration increases as more and more mass is displaced. Recall also that large amounts of power are required to operate the Lawson Effect, the containment fields, and the scoop fields. The fusion reaction cannot be throttled back below the point needed to power these critical systems, or below the point required to sustain fusion.

But, the Lawson Drive wants to keep accelerating. The mathematics of the Lawson Effect are complex. Lawson is said to have admitted privately that he didn't understand what physically happened to a Lawson Drive ship when it reached 0.7071c.

It is clear from the mathematics that at 0.7071c the entire mass of the ship is displaced. But what does this mean physically? From the best that researchers and historians can surmise, Felix Lawson was one of the first to find out.

At 0.7071c, the entire mass of the ship is displaced. At this well-named terminal velocity the entire mass of the ship turns into hard radiation (**Lawson Conversion**), spraying forward in space (**Lawson Shower**) in a highly collimated beam. As powerful and devastating as they were, ordinary nuclear reactions (**fission**) and even thermonuclear reactions (**fusion**) only convert a small fraction of available mass (less than one percent) into energy. In Lawson Conversion, the *entire* rest mass of the ship is converted to energy in the form of deadly radiation of mind-boggling intensity. As a result, the velocity of a Lawson Drive was carefully controlled.

Operation Problems of Lawson Drives

The Captain of a Lawson Drive ship who has survived startup and reached a cruising velocity of 0.7020c, allowing some safety margin, still has other matters of concern.

How wide is the safety margin? An unexpectedly rich pocket of interstellar gas will cause the power produced by the fusion source to jump very quickly. This can lead to a "bloom" failure, or if too close to terminal velocity, could result in Lawson Conversion.

Lawson Effect generators are large, complex, and emit prodigious amounts of radiation, some of which poisons the generators themselves (**Lawson Poisoning**), altering the composition and structure of materials at the atomic level. This radiation is also deadly to all organic life.

Remember that a certain amount of power was required to operate containment fields, scoop fields, and the Lawson generators. Also, the fusion reaction at the core of the ship could not go below a certain energy level. This set of requirements results in a certain minimum thrust level, which would normally result in acceleration and increasing velocity.

At close to terminal velocity, the speed of a Lawson Ship was controlled by adjusting the operating efficiency of the Lawson Drive generators (which were poor to start with). The set of generators could be “detuned” to cause more of their input energy to be released in the form of radiation, reducing the Lawson Effect but increasing Poisoning. With the Effect detuned, **relativistic mechanics** operates to slow the ship, allowing a steady velocity to be achieved under constant thrust. This has been compared to controlling the speed of a land vehicle not by reducing the engine speed, but by dragging large objects behind the vehicle. It is not efficient, and it is not pretty. But it did work.

What happens when (not if) the Lawson Effect generators failed?

Mass was “temporarily displaced” by the Lawson Effect. The mathematics Lawson Effect failure are complex, and the results grim. Imagine 98% of the mass of the ship has been displaced by the Lawson Effect. That leaves two percent of the mass of the ship traveling at close to 0.65c. When the Lawson Effect fails, the displaced 98% of the ship’s mass reappears -- at rest. Two percent of the ship is moving at significant fraction of the speed of light, and 98% of the ship is not moving at all. The resulting instantaneous devastation is the “**Lawson Skid**.”

A Lawson Skid could be distinguished from Lawson Conversion in that the Skid left a central smear of atomic debris, where Conversion left nothing but a flood of radiation. It was a distinction lost on the crew, passengers, or any life forms in the vicinity.

It was possible to slowly reduce the Lawson Effect through detuning, and this process was used for deceleration. The process of bringing a Lawson Drive ship into rest orbit around a destination is too complex to describe here. It had to be done very carefully to prevent Lawson Poisoning and fusion byproducts from rendering the destination uninhabitable and devoid of life. Evidence, or the lack thereof, of characteristic Lawson Poisoning in the materials forming the asteroid belt between Mars and Jupiter argue that if there was a First Age of Space, the Lawson Drive was not used, at least not as the weapon which destroyed the planet Atlantis.

Use of the Lawson Drive

With all these difficulties, Man in the Second Age of Space was able to make the Lawson Drive work. After the first decade, 50% of voyages were completed. After 50 years, this was up to about 75%. While official records from the end of the Second Age of Space are not entirely trustworthy, estimates are that about 90% of voyages from that period were completed. Most failures were still on drive startup. This made Lawson Ship launches a popular spectator event. The preferred viewing method was the use of high-powered telescopes and image relay systems, with intelligent spectators maintaining a safe and considerable distance.

Compared to the great sail ships, there is nothing esthetic about Lawson Drive Ships. They were not pretty. People making the trip (willingly or not) were placed in suspended animation, sealed in pods, and attached to the hull along with cargo pods.

Cyborg Ships

The syndicates operating Lawson Ships understood that time and mass were money, and the way to shorten the length of the trip and reduce the fuel mass needed was to increase acceleration, especially initial acceleration. While those in suspended animation were protected, the crew were not protected from the ravages of extended periods of high acceleration. Even at a fairly low acceleration of five (earth) gravities, four days of such acceleration is a death sentence to an unprotected human body.

In the third decade of Lawson Ships, the first cyborg ships were built. The reasoning was simple -- if high acceleration damaged the human body, then get rid of the body. The organic brains of the captain and a few other crew were built into the ship, directly connected to ship systems and the necessary life support equipment. Since the remainder of their bodies were not present, much higher acceleration could be tolerated, and higher radiation levels. While attempts were made to completely automate Lawson Ships, there is no computer as versatile for its size as the human brain. Cyborg based ships operated by a single crew member were the result.

At the start of the cyborg program, the captains and crews were volunteers, souls who had not only made Lawson Ship journeys, but lived to tell about it. While records of the time make this sound quite heroic and even romantic, recent research suggests otherwise. Even with extensive radiation shielding, which was often not provided, as radiation shielding represented mass which would otherwise be in the form of profitable cargo, the crew of a Lawson Ship suffered radiation poisoning to one degree or another. The cyborg program gave them the opportunity to discard their poisoned and dying bodies and make another trip to the stars.

The “416”

Probably the most famous of the Lawson Ships was the 416. Contrary to romantic notions it was not so named because it was the 416th Lawson ship built. It was named the 416 as those were the last three digits of the serial number of the convicted criminal who became its sole crew member.

The 416 held many records. It completed 19 interstellar voyages, six more than any other Lawson craft. It holds the record for highest sustained acceleration, 29.66g. It also led Earth's attack in the Battle with Bonus.

The Lawson Drive and the Battle with Bonus

Some historians still debate whether the Battle with Bonus was the First or Second Interstellar War. Many historians consider the destruction of the planet Atlantis, producing the asteroid belt between Mars and Jupiter orbiting Sol as the event which ended the First Age of Space and a result of the First Interstellar War.

As hideous as the Lawson Drive was, it captured perfectly the insanity of the end of the Second Age of Space. The inhabitable world Bonus was discovered and settled by one of the first of the Sail Ships. A stable society developed only to be “rediscovered” by an Earth-based Lawson Ship some two centuries later. Bonus was not interested in further settlement, nor did it consider itself an outpost or colony world behold in any way to Earth; animosity with Earth developed. Bonus produced Lawson Ships of its own. Even though it took decades of planet-time to exchange each round of insults and animosity between groups on Bonus and Earth, Man found a way to do it, and to foment war.

We know now that even separated by many light years, both Bonus and Earth decided to attack each other, and launched their fleets within five years of each other.

The weapon of choice was the Lawson Ship.

Both sides had the same technology, and about the same understanding of it.

From their contemporaneous records, we know Bonus launched a fleet of 29 ships, with a staggering 15 ships lost to startup failure. Earth launched 20 ships, led by the 416. Four Earth ships were lost to startup failure.

The people of Bonus knew they were building and launching a war fleet. In his speech to the people of Earth announcing the launch of the 416, the Chairman of the Central Committee described the Earth fleet not as a war fleet, but as “a glorious expedition of peace and exploration.”

The proportionally large number of startup failures were not explained on Earth. Hypotheses existed, but were suppressed. The well-preserved records discovered by archaeological expeditions to Bonus during the Third Age of Space provided many answers.

Both sides had the same technology, and made similar decisions. For maximum power and destruction, rather than fueling the ships with simple hydrogen, both sides included rarer radioactive isotopes of hydrogen, deuterium and tritium. These isotopes provided more power, but also made successful startup more difficult.

What weapons did the ships carry? Themselves. While Earth’s strategy was not recorded, historians and archaeologists recovered records of the debate on Bonus. The choice was among three deadly strategies. In the first, the ship would impact the planet at close to terminal velocity. In the second, the ship would undergo deliberate Lawson Conversion as close to the planet as possible, showering the planet with deadly radiation. The third strategy was to cut containment fields and the Lawson generators as the ship entered the planet’s atmosphere, allowing a deliberate skid and bloom, again while traveling at close to terminal velocity.

Bonus’s approach was a mix of all three, staggering ship launches and projected travel times to have ships arriving at Earth in waves separated by multiples of eight hours, a third of a planetary rotation. Launch records for the Earth “exploration” fleet suggest a similar plan.

Of the sixteen ships successfully launched by Earth, fourteen arrived at Bonus. The first to arrive was the 416. All fourteen ships either impacted the planet or converted near it. All life on or near Bonus was extinguished.

While Bonus had not prepared a defense, Earth fared better. Historical accounts are unclear as to whether the defense was organized by the ruling Central Committee, or by those who overthrew them.

The giant lasers used to launch the Sail Ships of old were brought back into service.

But what damage could a laser, a mere beam of light, do to a ship with a rest mass of some hundred thousand metric tons, hurtling inward at close to $0.7c$? The lasers were tuned to specific wavelengths which would greatly increase the efficiency of the fusion reactions in the thermonuclear source at the core of each ship.

Nine ships approached Earth from Bonus. Six were destroyed well outside the orbit of Mars, the lasers causing them to bloom or convert.

Three ships remained. They accelerated towards Earth. As they accelerated, one skidded on its own. One of the two remaining was driven to conversion by the lasers.

We will never know what the captain of the last ship, or any of the ships, thought. We do know that he (or she) maneuvered to use the Earth's sole Moon as a partial shield. The launch lasers tracked the ship as best they could, destroying one lunar outpost and further scarring the surface of an already scarred moon.

One laser crew directed their beam through the outer edge of the Earth's atmosphere, hoping the atmosphere would bend the beam just enough. It was just enough, and the final ship converted, less than two light-seconds from the planetary surface.

The resulting radiation shower grazed the surface and atmosphere of Earth, killing hundreds of millions, and sterilizing part of a continent.

The Battle with Bonus was over. So was the Second Age of Space. Once again, Man on Earth descended into **The Darkness**.

Metric Drives

Where the Lawson Effect displaced small amounts of mass, **Metric drives** operate directly on the metric or fabric of space-time (see **Uchida, Minami; Gutierrez, Frans Josef**). They are the basis for **artificial gravity** as well as drive systems. While their theoretical basis is complex, their implementation is compact, simple, and efficient. Even though the relativistic limitation of the speed of light remained, craft could accelerate quickly and safely to very close to the speed of light, and decelerate just as easily, quickly, and safely. Modern metric drives achieve accelerations and decelerations on the order of 20,000 gravities, consuming surprisingly small amounts of power. With the relativistic “slowing” of time with respect to the crew traveling at close to the speed of light (see **Relativistic Mechanics**), journeys to nearby stars could be completed in short periods of time, from the crew’s perspective at least. Still, a round-trip to Hoodah, some 23 light-years distant, requires almost 50 years from a planetary perspective.

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