# AMERICAN SPACE PARALYSIS

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*Is the American shuttle finished? It's hard to escape this conclusion on analysing the file on the Challenger catastrophe. A damning criticism of the organisation and the men of NASA, the know-how of certain people in industry and the future of the American space programme.*

When it happened, the shockwaves were a result of the horror of watching seven astronauts reduced to smoke and dust in a fraction of a second, in front of one's eyes. Seven astronauts, including a young woman teacher Americans had fantasised about for months were killed. It was the 55$^{th}$ manned American launch (the 25$^{th}$ for the shuttle) and it was the first time such a thing had happened, at least, in flight.

But now the real reasons for this cruel disaster have been revealed. It was not a passing failure or an unlucky accident, but the logical and unavoidable conclusion of a catalogue of errors: a space programme that was too ambitious, based on fundamentally flawed techniques together with an underestimation of the competition from Ariane, and finally, relentless pursuit of success in defiance of common sense and a last minute rushing to catch up in impossible circumstances; resulting in safety being relegated to secondary importance.

Let's take a look at what happened: The night before the launch, it was exceptionally cold for Florida. At the Kennedy Space Center, the shuttle was in its vertical position, ready for launch, attached to its fuel tank of hydrogen and liquid oxygen, which in turn was fixed to the two booster rockets, the two big powder fuelled rockets which ensure take off. Imagine the vastness of this missile about to be sent into space for the 25$^{th}$ time. It's as big as a 15 floor building. The boosters and the external fuel tank are each over 45 metres high. The whole thing weighs more than 2000 tons. 2047 tons, to be exact: the heaviest space vessel ever launched by NASA since the beginning of the shuttle programme. It is now January 28th. The monster is there, on its brand new launching pad. It has been there since December 21st, five weeks of mostly inclement weather including torrential rain. The launch had been postponed twice because of bad weather.

On the night of the 27th to 28th, an icy wind blew from the North-west. A wind of 8 knots, with highs of 16 knots. The temperature fell to -4.4°C. In the small hours of the morning a team of specialists came to remove the ice. The air temperature rose but it remained the coldest ever recorded prior to a shuttle launch: 3.3° according to NASA, below 0° according to other sources. It is sure, however that the "ice" team measured abnormally low temperatures on the lower part of the surface of the booster on the right: -12.7° and -13.8°. NASA later contested the accuracy of these temperatures and came up with -7.2°. However, this figure is no more normal than the others. How can they be explained?

Tests carried out in a wind tunnel over a year before may provide the answer. The booster was facing east. The north-west wind, before reaching the booster, swirled around the external tank. This tank was very cold as it had just been filled with hydrogen and liquid oxygen at -252.7° and -182.7°. Despite a good solid layer of insulation, the surface temperature of the tank oscillated between -13.3 and -16.6°. The wind therefore cooled on contact with the tank throughout the night, forming freezing cold eddies round the lower third of the booster.

These boosters were the most powerful solid fuel rockets ever made. The design was based on a very old model, that of the first stage of the strategic Minuteman missiles, operational in 1963. It was not possible, technically, to build them in one piece. They were made up of 11 basic segments, these in turn were combined to form four "primary" segments, which were fitted into each other two parts at a time. The seals had to be perfectly hermetic. Otherwise, flames of over 3000° would burn their way through to the exterior.

"Powder" fuel in fact has a consistency of hard rubber. Each booster contains 500 tons, distributed between the four segments. Combustion takes place over the full height of the booster from a hollow channel running down the centre, but each segment burns separately. The fuel is embedded in a layer of insulation which separates it from the fuel in the next segment and from the outer steel surface. 600 milliseconds after ignition, the engine is already at maximum speed: 1495 tons of thrust. The force of the shock causes the outer steel surfaces to stretch and swell. The join between two segments is put under extreme pressure. Although bolted together by 177 powerful steel pins, the surfaces of the two segments pull away from each other.

The burning gases head straight for the breach. A complex and mobile device normally prevents them from doing so, however, in this case, it apparently was this device which failed and was the direct cause of the Challenger explosion. There is a layer of mastic between the insulation of the upper segment and the insulation of the lower segment right next to the breach. On ignition, this layer of mastic comes under pressure from the gases and compresses the air in the breach. This pressure causes a thin band of rubber to move and block the breach at a specific point. When not under pressure, this rubber “band” which goes all the way round the booster lies in a groove in the steel surface. For safety reasons, there is a second identical band in a groove just below the first one, so that in the event of the first band not doing its job, the second one blocks the breach a little lower down.

Most experts consider this to be the cause of the explosion. Already fragile, it did not stand up to the low temperatures in the hours prior to take-off. The mastic and the rubber are sophisticated materials, but the cold causes them to lose their elasticity, harden, and even break. The vast quantities of rain during the preceding weeks possibly aggravated the problem by getting into the grooves and freezing.

It is now possible to imagine the events during the 74 seconds of the tragedy.

Less than half a second after ignition, while Challenger was still on its launch pad, a cloud of black smoke appeared between the external fuel tank and the lower seal of the booster on the right. The black smoke meant that materials contained in the mastic and the rubber were burning.

59 seconds later, the shuttle had been subjected to its maximum in terms of dynamic pressure having gone through some turbulence and there was an intense white flame level with the lower seal of the booster. The flame moved straight towards a vital part of the vehicle: the fitting which attaches the lower half of the booster to the external fuel tank.

13 seconds later, the fitting snapped. Fuel tank n°2 was inevitably affected. The enormous booster (at 3000 kph) swung away and hung from its one remaining fitting, near the front. In a fraction of a second, the rocket booster slammed into the fuel tank while its back skirting hit the right wing of the shuttle which normally overshadowed it. Meanwhile, the flame emerging from its side was burning the surface of the shuttle.

The inevitable occurred: the fuel tank was almost certainly holed in two places, the oxygen and the hydrogen mixed together, and then came the explosion. The explosion started near the fitting at the front 73 seconds and 226 milliseconds after ignition. The last piece of data was transmitted 308 milliseconds later. This didn’t stop the official NASA commentator announcing unperturbed "1 minute 15 seconds, speed 884 metres per second (3182 km/hr), altitude 16.6 km..." But the screens suddenly went blank.

Shuttle take-offs are entirely controlled by computer. The flight commander has no means of reacting to anything whatsoever. The reason is simple: Once the boosters have been ignited, there is no way of stopping them. You cannot prevent combustion. The whole space vehicle is linked to the boosters right up until total combustion, as in the case of fireworks. If all goes well, the boosters are released within 130 seconds. They come down by parachute and hit the surface of the sea at a speed of 150 kph. They remain on the surface and emit signals until someone comes and recovers them.

This time, however, the boosters were destroyed. Not by the explosion of the fuel tank but by the air force. The two boosters were continuing their descent. One of them was likely to crash in Florida. They were destroyed by remote control that apparently worked fine. Like the rest of the Challenger debris, their remains were scattered on the sea floor.

How is it possible that no warning signals appeared on the command screens? Everything indicates that not even the crew were aware of anything amiss. The answer is clear: there were no temperature sensors in the boosters, and the pressure sensors fitted were not sophisticated enough to set off alarm signals. Not that it would have made any difference if there had been such sensors as there is absolutely no way of carrying out a rescue operation before the boosters have been released.

The 2000 ton monster was hurtling through the air at over 3000 kph, driven by engines that were totally out of control. All one could have hoped for was for the shuttle to detach itself from its hydrogen/oxygen fuel tank. But there it was, hurtling through the atmosphere with dynamic pressure at its highest: the shuttle out of control, catastrophe was inevitable.

Sensors, nevertheless, would have helped to identify the cause of the catastrophe. But as we shall see, NASA had allowed for as few sensors as possible in order to decrease the payload. The shuttle had another weakness: it did not have powerful on-board computers. Its four IBM computers were excellent but dated from the 70’s. Each one processed under half a million operations per second, less than many PCs today! However many sensors had been fitted, it would still have been necessary to choose between information that could be processed on board and the much larger quantity of data transmitted directly to earth to be processed after the flight.

An internal NASA memo states that a press conference was to be called within 20 minutes of a major catastrophe. On January 28th, it was seven hours before Jesse Moore, the man in charge of the shuttle programme, and who had ordered the launching, agreed to appear. He denied having any information concerning the possible causes of the catastrophe, he simply announced the setting up of an enquiry to be headed by himself.

Although it was not usual practice, he had the 100 odd fixed cameras around the launch pad seized. They belonged to various press agencies and private companies. As a result, both the media and the public were entirely dependent on what was released and shown on television. No help at all to those trying to understand what had happened.

In the days following the catastrophe there was something that closely resembled an attempt at a cover-up. NASA gave no information and claimed to have none. The people in charge said they did not understand what had happened. NASA engineers and the companies who participated in the construction and maintenance of the shuttle were sworn to secrecy.

But American journalists started searching and investigating. Inside NASA but also inside the companies concerned, certain people were willing to talk, on condition their identity was not revealed.

Thus it was via the Press that we learnt on the very first day that there was a serious problem of temperature. NBC radio identified the seals of the rocket on the right during the evening of the 30th. This piece of information was confirmed and developed by *The New York Times.* Finally, during the evening of 1st February, NASA consented to show a sequence of photos showing a bright orangey-white light on the lower part of the rocket. But the head of NASA, William R. Graham, was not entirely sure that it really was a flame. He added that the boosters were considered "virtually infallible".

It was also via *The New York Times* that we heard on February 2nd, that there was no way the computers on board could detect a leak of burning gas from the booster. And also that no rescue was possible during the first two minutes of the flight. However Graham maintains the astronauts could have separated the shuttle from its fuel tank and therefore from the boosters, and even attempted to land on Cape Canaveral.

All this was beginning to create a bad impression. On February 3rd, President Reagan announced the setting up of an independent inquiry to hand in their report by 1st June. It was to be headed by William Rogers, former Secretary of State (minister of foreign affairs). He was 74 years old, knew next to nothing about the space industry, but was renowned for his common sense. He was assisted by two astronauts, both technology and space industry specialists, and a famous physicist, Richard Feynman, 1965 Nobel peace prize.

The Rogers commission started to hold in camera hearings and carried out on the spot investigations, a series of public hearings and broadcasts on television reminiscent of the Watergate hearings. People at NASA continued to say as little as possible. Meanwhile, the Press spilt the beans time and time again. Increasingly irritated, Rogers opened hearings with the following words: “I just read in the Press...". Little by little, the image of the most prestigious of America’s institutions cracked and frayed at the edges and finally disintegrated.

The commission concluded that not only should NASA never have launched Challenger, but it should have brought the whole shuttle programme to an end six months earlier. A growing number of observers started to wonder if the United States shouldn’t thoroughly re-think their space programme, give up on the shuttles, think of something completely new...

Here is a summary of what we learnt from the Press and from the Rogers Commission public hearings:

- NASA knew that the boosters were the Achilles heel of the shuttles.
- It knew that the failure of a single seal would be fatal.
- It had no contingency or solution for the problem.
- To increase the payload, it had made the boosters lighter in weight while increasing the power of the motor thus rendering the boosters still more vulnerable.
- Under the growing threat of increasing competition from the European launch Ariane, it speeded up inspection and checking procedures.
- On 28th January, it totally disregarded the advice recommending they not go ahead with the launch. This advice came from the engineers of the company that made the boosters and the top management of Rockwell; the main builders of the shuttle.

Let’s turn to each of these points in detail. Right from the first test flight of the shuttle, NASA was concerned about the vibrations caused by the combustion of the boosters. These vibrations could be felt right inside the cabin of the space shuttle and the flight commander remarked “everything’s got the shakes in here”.

NASA sought the opinion of Gary Flandro, professor of aeronautics at The Georgia Institute of Technology. He concluded that the vibrations indicated combustion instability due to the segmentation of the motor. He believed it to be a dangerous phenomena: if the oscillations exceeded a certain level, the as yet unburned fuel could be

put under excessive strain, causing cracks to appear and increasing the likelihood of burning gas escaping; rather like what did in fact happen in the Challenger catastrophe. Flandro recommended that NASA should suspend flights while the problem was solved. NASA decided the problem was of secondary importance and chose to ignore this advice. Flandro's opinion was nevertheless confirmed by the presence of sensors in the boosters on three of the following test flights. On one of the flights, oscillations three or four times greater than normal were registered. When questioned about the flight of 28th January, Flandro declared the cold may have aggravated the problem.
A NASA document dated 17th December 1982 included the booster seals in a category of elements considered to be among the most "critical" of the whole space vehicle. They were classified "risk 1", and were now part of the many components which, if they failed, would result in catastrophe. Tests showed that the pressure exerted at take-off on the segments of the booster caused a larger than expected opening (referred to elsewhere in this article as a breach). Vents opened up in the mastic. Bits of mastic and burning gas jets were ejected in the direction of the rubber circles. The report specifically says that if a seal were ill-fitting at take-off, the second circular rubber band - last bastion against a catastrophic leak - could be irrevocably damaged.

NASA has a contingency called the "redundancy" rule. This rule requires there to be a double for every vital part. Unneeded if all goes well, but backs up the faulty part in the event of failure. If a shuttle computer breaks down, its functions are immediately taken over by a second computer. Obviously, this rule cannot be applied to every single component. In which case, the absence of a "redundant" part must be made explicit. In March 1983, NASA classified the booster seals amongst those parts exempted from the "redundancy" rule.

In December 1983, a confidential report requested by the US Air Force was handed in to NASA. It was written under the authority of Weatherwax, an aeronautics engineer who headed a company specialised in risk assessment. This report analysed 2000 mainly military "booster" launches using the same technology as that of the shuttle. It concluded that the chances of destruction during flight were 1 in 35, given the changes in technical applications. 100 times higher than the chances of dying in a car accident: 1 in 4,000.

This report judges NASA's risk assessment methods to be "inadequate" and to "raise major problems". The 3rd May 1984, US Air Force experts judged this report to be "credible and significant". 1 in 35! Challenger was n° 25... or n° 50, if you take into account the fact there are two boosters per shuttle! This clearly was not NASA's point of view. In 1985, the space agency published its own assessment: 1 in 60,000...

In January 1985, for the first time, a shuttle did almost finish up the same way as Challenger. This was Discovery on a military mission. During the previous night, the temperature had gone down to -3.9°C. It went back up to 11.6°C at take-off. Photos show a puff of black smoke coming out of one of the boosters. Inspection of the seals after the flight show that two of them had been eroded. In one case soot was found between the two bands of rubber. The second band, the "last resort" band had been damaged by the heat.

29th April 1985, it was Spacelab's turn to come close to catastrophe. Spacelab was attached to Challenger. This time, the first band of rubber did not shift as it was supposed to do, it allowed gases to escape which in turn triggered the second band but also caused it to deteriorate.

On the 11th July, Irving Davids, a NASA engineer who specialised in boosters, went over the problem of seals with the Marshall Space Center engineers who supervised the assembly of the boosters. He drew up a list of 17 cases of erosion. He sent a memo to Jesse Moore, the big boss of the shuttle programme: "the consensus is that if the first band does not do its job, the second is not a reliable back up."

On the 23rd July, Richard Cook, a 39-year-old budgetary controller, sent an alarming report to Michael Mann, the financial manager of the shuttle programme. He wrote that the "carbonisation" of seals observed during previous launches constituted a "potentially major problem affecting both the safety of the flights and the cost of the programme". There are documents that testify to the fact that this warning was passed on to the higher echelons of the organisation.

A few days after Cook, Roger Boisjoly, an engineer considered by NASA to be a top seals specialist also sent a memo to his superiors. He wrote that the question of whether the seals would hold or not was luck of the draw, and if they didn't hold, "the result would be a catastrophe of the first order, involving loss of life ".
So NASA knew perfectly well the boosters were the Achilles heel of the shuttle and that the failure of a single seal would be fatal. Nevertheless, it had made no attempt to solve the problem. It had not taken up the offer of Morton Thiokol, the firm which built the boosters, to develop new seals. 19th August 1985, Morton Thiokol had offered no fewer than 43 alternative solutions to the NASA engineers...

Rightly or wrongly, NASA felt a gun was being held to their collective heads and were under intolerable pressure. They were behind and they had underestimated competition from Ariane.

In 1981, when the first shuttle was launched, the programme was three years behind and cost twice as much as originally budgeted. In addition, the shuttle did not satisfy Ministry of Defence requirements for financial participation: a payload of 27.2 tons.

By 1981, NASA expected the programme to be fully operational, even routine, but in 1985, instead of the 24 expected flights, (one every two weeks), there were only 9 shuttles (as against 4 in 1983). 15 flights were planned for 1986.

Flights were behind because of technical problems. There were many major incidents. The four best known: 18th December 1982, a hydrogen leak was detected by accident just before a Challenger flight. The enquiry demonstrated that the leak would have caused the explosion of Challenger within the first two minutes following ignition. In October 1983, it was discovered after a flight that the gas exhaust tube had been almost completely holed. One half centimetre more and there would have been flames causing either an explosion or a spectacular accident: the space vehicle spinning round completely out of control. 26th June 1984, the countdown stopped for 4 seconds before take-off because of a breakdown due to shuttle engine no.1. There was a fire at the back threatening to engulf the vehicle. The astronauts spent 40 minutes waiting with their hair standing on end while engine pressure came back down to normal. The 29th July 1985, not long after take-off, failure of a turbo pump caused the shuttle engine to cut out. This caused the shuttle to settle within a lower orbit. If the failure had happened sooner, the shuttle would have had to make a hazardous landing in Greek waters.

Meanwhile, Ariane was notching up success after success. After a first flight in 1981 Ariane had had 13 successful flights out of 16 by February 1986. Its capacity was very much lower than that of the shuttle but was increasing, the number of launches likewise. With the same payload Ariane was a great deal cheaper. And did not put lives in danger.

In the United States, the Ministry of Defence could feel the wind change. It had financed half the shuttle programme and was its main client. They started to have doubts about the profitability of the programme and wondered about the wisdom of putting all its eggs in one basket: if the shuttle programme were to stop, it had no other way of launching military satellites and carrying out required tests for the SDI (Strategic Defence Initiative) more commonly known as “Star Wars”. Therefore, while investing 3 billion dollars in the construction of its own shuttle launching pad in Vandenberg, California, Pentagon managed, in 1983 and despite opposition from NASA, to obtain permission from Congress to build around ten non-recoverable rockets with the same payload as those of the shuttle. These were due to be operational as from the end of 1988.

In this context, there were many signs that the atmosphere at NASA was beginning to change. George Robinson, a legal consultant who was very familiar with NASA said the agency had for ten years been dogged by an attitude that said: "We will fly, no matter what"'. And thus, the old notion "safety first" became redundant. This was just before Challenger exploded. NASA internal safety committees had recommended that NASA be less ambitious. The forecast of 18 flights a year in 1987 was judged to be "very optimistic". 12 to 15 flights was considered reasonable though "still difficult to achieve". One of the members went further saying that launching a shuttle was not the same thing as an airline take-off: "It would be very dangerous to slavishly conform to a specific number of flights per year", he said. As a witness for the Rogers commission, Richard Cook, the budgetary analyst who had warned NASA about the dangers of the "carbonisation" of the seals, noted a "it’s sure to work” culture inside NASA, promoting the idea that somehow all problems would get solved on the way to reaching the ultimate objective.

On a technical level, several near disasters, mainly related to the boosters, did not stop NASA playing with fire: in order to increase the payload, it increased motor capacity as if it were in a balloon race, by throwing overboard everything it considered superfluous.

By 1983, booster thrust had increased by 90,600 kg, so capacity was up to 1,495 tons. One of the operations responsible for this increase in power consisted of modifying the fuel composition at the base of the two central segments. Instead of only burning laterally, these two segments burnt both laterally and vertically. This was one of the points brought up during the Challenger enquiry: this double combustion mode modified the pressure on the two segments which may have been subjected to abnormally strong vibrations.

At the same time, the boosters had been lightened in weight. The steel surfaces of the two central segments plus the lower segment had been made thinner and thus each booster gained almost two tons in capacity. The surface of the external fuel tank had also been made thinner thus gaining five more tons. Even the white paint on the fuel tank had been removed making a saving of 272 kg!
Not satisfied with that, NASA turned to the equipment, more especially the sensors. Flight by flight the number of sensors (which transmitted information to the computers) was cut by half both in the boosters and in the shuttle. According to the insurance company Lloyd's of London, nearly 5 tons

of sensors and other instruments had been removed. Challenger's total weight, not including payload, was around 20 tons less than on its first flight. And that was not all! NASA was getting ready to replace the steel surfaces with alloys.

Not everyone approved of this race to lighten the vehicle in weight. Insurers were not alone in asking questions. In 1983, in a report to Congress, NASA's own safety committee wrote in black and white that attempts to increase the payload would result in “a probable decrease in safety margins". In the same report, the committee said time constraints "may have an impact on the quality of verification tests". The fact remains that preparation time for each flight went down from 100 to less than 50 days. A “record” of 27 days was reached. All this rushing may have been the cause of several incidents in the assembly plants. 8th March 1985, a huge skip fell on the door of the hold of Discovery. The result: one person injured, 200,000 dollars of damage and two weeks delay. NASA determined that Lockheed, who had the whole shuttle programme maintenance contract, had broken safety regulations. In May, three top managers of Lockheed in the Kennedy Space Center were replaced.

On 8th November 1985, during the assembly of the left Challenger booster in the Kennedy Space Center, the front segment was mishandled by a crane and rendered useless. The NASA report concluded the technicians involved in the operation were inexperienced, unmotivated, and used faulty material. This 176 page report dated 13th December was headed: "the team lacked discipline" and contained sentences such as "I was doing something else when it happened", "I only look after things I'm responsible for", "It's not my job".
And finally on 25th January 1986, between two Challenger flight reports, the surface of the external fuel tank of the shuttle was damaged superficially by the arm of a lifting apparatus. This was judged to be minor damage, nevertheless, that was a lot of accidents for just one year.

When the last accident happened, the pressure was at its greatest. On the 18th, the Columbia shuttle had just landed in California, (not in Florida as intended) having spent three days orbiting round earth unable to land because of weather conditions. This was considered a catastrophic state of affairs. It came after more than three weeks delay when launching was postponed five times due to four technical incidents. Columbia's return on the 18th meant that it was unlikely to be able to meet up with the Haley comet on 6th March. Worse still, this affair endangered the Challenger launch and also that of the space probe *Ulysses* to Jupiter. The whole 1986 programme was under threat.

The Kennedy Space Center team was tired and under strain. It had to keep going, look after Challenger, on hold since 21st December. Challenger was supposed to be launched on 23rd January, but the Columbia problems delayed the launching till Saturday 25th. But then, as we have seen, it was further delayed till the 26th and then the 28th because of poor weather. Jinxed, without a doubt. Moreover, the mission was symbolic because, for the first time ever, there was a civilian on board, a woman, a young history teacher called Christa McAuliffe. Reagan decided on this during his electoral campaign in 1984. Politics were Reagan's speciality. Little Christa would teach her class, via a television screen, during the flight. Reagan had planned to talk personally to the astronauts in flight right in the middle of his State of the Union speech. This speech was to be on the 28th. Never, in American memory, had this date ever been altered…

So when on the 27th the weather forecast announced plunging temperatures for that night, people were anxious. It was a well established fact that the seals, not too reliable in normal conditions, were downright fragile in the cold. The serious accident of the previous January when the cloud of black smoke appeared for the first time, happened in the lowest temperature ever recorded at a launching (11.6°C after a night at -3.9). This time, even colder temperatures were forecast. Possibly 10 or 15°C colder!

At 4pm, after a discussion with colleagues, Robert Ebeling, Thiokol engineer at Cap Canaveral told McDonald he was worried. The latter took him seriously. He called Robert Lund, Vice-president of Thiokol, who had the upper hand in engineering issues. He decided to organise a teleconference with NASA top management in order to decide what action to take.
Why a teleconference? Because decision centres were scattered. A geography lesson is called for. Cape Canaveral, the launch base, is at the Kennedy Space Center, on the Florida coast. That is where the people in charge of the launch were. But with regard to the delicate and highly technical question of booster seals, a chain of decision makers had to be consulted.

When the boosters are fished out of the sea after a successful launch, Morton Thiokol boats tow them all the way to Kennedy, where they are disassembled and get their first cleaning.
From there they go to Morton Thiokol factories in Utah, where the pieces are processed and reassembled in order to make up the four primary segments. These are filled with solid fuel by Morton Thiokol who then sends them by rail to Kennedy, where they are assembled in pairs.

The technical supervision of all these operations however is carried out by another player in the system: the Marshall Space Flight Center, in Huntsville, Alabama. Like the Kennedy Space Center, it is an integral part of NASA. It is responsible for checking that NASA contractors and sub-contractors conform to contract specifications. If there is an incident, in flight or on the ground, it is up to the Marshall Center to investigate it.

The teleconference of 27th January was therefore a tripartite discussion between the headquarters of Morton Thiokol in Utah, the Marshall Space Flight Center in Alabama and the Kennedy Space Center in Florida.

The teleconference started at 8.45pm. The protagonists had had five hours to prepare. The fifteen odd Thiokol engineers, in Kennedy and in Utah, clearly expressed their opposition to the flight. The aforementioned Robert Lund, vice-president of Thiokol declared that he would oppose the flight for as long as the temperature did not reach the minimum temperature of January 1985 – 11.6°C. In NASA however, there was consternation on all sides. In Huntsville, George Hardy, the no. 4 of the Marshall Space Center said he was "appalled" by this attitude, whereas in Kennedy, Lawrence Mulloy, in charge of overall supervision of the boosters in the Marshall Space Center, exclaimed "Good God, Thiokol, when do you want me to launch, in April?".

After two hours of discussion where no-one gave way, Joseph Kilminster, vice-President of Thiokol for the boosters, who had also been against the flight, asked for a session break. Half an hour later and on Jerald Mason's request, he recalled the "senior" vice-president of Thiokol who agreed to go back on his original decision and signed a document where Thiokol authorises the flight.

This document was immediately faxed to Kennedy. It is stated in this document that the bands of rubber round the boosters would be, according to calculations, 11°C colder than when the shuttle was positioned in January 1985, that the seals would lose their elasticity, that the first band would almost certainly not do its job, but that the second should hold up.

Taken aback by his company's decision, Allen McDonald, the chief engineer at Thiokol present at Kennedy, tried to sway Lawrence Mully. "If something goes wrong", he said to him, "I wouldn't like to be in the shoes of whoever has to explain to the commission of inquiry why he authorised the flight".

From then on, responsibility began to drift away. It was impossible to know who should have been or had been informed about what, in particular, the alarming temperatures recorded on the booster on the right. In the morning, top managers at Rockwell, the main shuttle constructor, were worried about the ice that had formed on the launch pad. The vice-president of the company, Robert Glaysher, said to Arnold Aldrich, one of the top brass at NASA, that his company "will not answer for the safety of the flight". Aldrich remained unperturbed. Two hours later, countdown had started and the shuttle set off for its destination. The astronauts did not know there was a problem with the boosters, no one had informed them.

## The USA goes back to unmanned flights

The Americans bitterly regret having put all their eggs in one basket. Even if, in a best case scenario, the shuttle programme is interrupted for no longer than 18 months, the consequences are enormous.

It is not that the United States have nothing else but the launchers they have are entirely reserved for the Army. Also, they have a modest capacity, their payload is full and they hardly constitute an alternative solution.
If the programme starts back up summer 1987, it will start slowly and carefully, using three out of four shuttles. They will be about thirty missions behind.
The delays will accumulate over the years. As military flights have absolute priority, the first two years will be almost entirely dedicated to military missions. Second in line are commercial flights: so scientific flights will be put off indefinitely.
Such is the fate of Ulysses (to solar poles) and Galilee (to Jupiter) programmed for this year. such is the fate indeed of the space telescope due to be launched in 1986.

Even if all goes well and a new shuttle is built to replace Challenger, the delays would make themselves felt for several years. The construction of the space station, planned for the middle of the 90's, would be affected. Its assembly requires no fewer than 12 to 18 shuttle flights, and its maintenance requires an ongoing 9 flights a year. The space station was designed for the day when the shuttle would be a space bus. That day is still a long way off.

And what if there are accidents? Or a shuttle were damaged? Supposing the only Boeing 747 able to transport the shuttles between the east and west coasts of America had an accident? Will a new shuttle ever get built? It would cost 3 billion dollars to build, which is half NASA's present budget. The United States is going through a serious budgetary crisis, and Congress is unwilling to foot the bill. If there is no new shuttle, the United States will have to abandon the space station which would cost 12 billion dollars to build. This would have a backlash effect on the European shuttle project Hermès, designed with the space station in mind, and it would lose a part of its raison d'etre.

The Americans cannot afford further delays. They need to develop and perfect their telecommunications networks for civilian purposes and even more so for military purposes. They want to be able to carry out experiments related to “Star Wars” as soon as possible. Washington cannot wait for NASA to bandage up its wounds or for astronauts to feel able once more to embark on a shuttle. Indeed, the decision to re-launch unmanned flights has already been taken. In the best case scenario, the American space programme will henceforth be a mixed programme made up of two shuttles and unrecoverable unmanned launchers.

What will these launchers be like? Most probably, to start with, three rockets of the same Titan category. These were originally designed to carry nuclear warheads, but they can also be used for putting objects into orbit. By strange coincidence, they are built by Martin Marietta, who made the external fuel tank of the shuttle. Low end rockets, Titan 2 are already being converted. They will be able to put loads of just under 2 tons into low orbit.

Titan 3407 are middle end rockets. They can put 12.5 tons into low orbit. The air force owns 7 which were ready for use before the Challenger catastrophe. Production could be restarted.

Titan 34D7 are high end, The U.S. Air Force, who were worried about the possible failure of the shuttle, had managed to obtain authorisation to order 10 in 1983. The first ones will be delivered in 1988. Their capacity is identical to that of the shuttle (that is to say, they can carry over 20 tons into low orbit). They can also be mass produced.

These military launchers can also serve to put American civilian satellites into orbit. Some of these may instead use the launcher Ariane. The European rocket is still a long way off having the same capacity as the shuttle but it can replace the shuttle for certain types of satellite. Arianespace has offered shuttle customers a total of 8 payloads during 1987 and 1988.

Private companies like General Dynamics and Transpace Carriers may also get into the business of producing launchers for civilian telecommunication satellites. There could be a market for launchers alongside NASA and the army. Who knows, maybe one day there will be a new and unusual type of launcher.