Air and Space this Week

Item of the Week

NASA SPINOFFS 1976: THREE VALUABLE BENEFITS

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I like to look at NASA's founding documents from time to time, including the National Aeronautics and Space Act of 1958. It's "Declaration of Policy and Purpose" sections align well with the Smithson bequest to support "the increase and dissemination" of knowledge. NASA technology, products, and management impact all aspects of our modern life. Some you know about, some are misunderstood, and many are ones that are less-generally known, having come before many decision-makers of today were born.

This particular "Item of the Week" spotlights three stories from 1976 about how technology developed by NASA for Spaceflight turned out to be valuable commercial products.

NASA has an entire Technology Transfer section devoted to meeting its Charter requirements by making NASA technology available to commercial applications, providing valuable products while generating jobs and other economic stimulation.

INTRODUCTION

Ahhh, 1976! The Nation's Bicentennial. In this Year of the Cat, we listened to Wings, danced to Disco, and wondered if Pink Floyd could duplicate its recent successes, all while *Bohemian Rhapsody* rhapsodized us. Viet Nam and Watergate were in our rear-view, while three guys formed a company in a garage, bizarrely calling it "Apple," the Reds whipped the Yankees, and the Steelers won the Super Bowl.

The amazing feats of Apollo were in the recent past, and NASA was eager to follow-up the success of *Mariner 9* with a much more capable Viking while planning for a Solar System Grand Tour. Meanwhile, many technologies created initially to aid NASA in its lunar quest were being utilized to generate jobs, acquire resources, and make travel safer for all Americans.

I have selected three of them, among the many, many others, for a more detailed look for you: anti-corrosion paint, grooved pavement, and the Alaska Pipeline.

ANTI-CORROSION PAINT

NASA has struggled with maintaining its facilities at Cape Canaveral since it was built. Corrosion of metallic structures was a big problem, since the Space Center was built in an area surrounded by brackish water and salt spray. They had worked with corporate partners before in the development of paints that would provide some protection from corrosion, and the partners were glad to do so since such paint would have much broader use than just NASA facilities.

The development process produced improved paints, but the research into making even better ones continued from those early days. NASA even built its Corrosion Engineering Laboratory at KSC, with a test site on the beach; it has had a 50+ year record of providing information on the performance of various anti-corrosion measures and is still in full operation today.

NASA made a major breakthrough in corrosion protection in 1976, with the development of zinc-rich anti-corrosion paint. It was not only tested at the CEL, it was also applied to part of the Golden Gate Bridge. The GGB was a good test subject, since it required a team of 42 painters to be permanently employed in applying the then-conventional paint, which lasted only a few years. The new zinc-rich paint was easier to apply, provided better corrosion protection, and lasted considerably longer than the paints it replaced. The new paint was embraced by manufacturers, becoming a $2B annual business almost immediately (equates to $11.5B in 2024 dollars), and has grown considerably since. Zinc-rich paint, and products developed from it in the half-century since its initial use, now protect bridges, ships, drilling rigs, utility pipelines, and other steel structures in coastal or otherwise-hostile environments. The anti-corrosion coatings market is expected to expand at a rate of over $8B annually.

The Corrosion Research Lab's sites at KSC and the surrounding area were upgraded in 2010 and monitored more closely and regularly for chloride concentration from salt air and corrosion rate. The sites ranged from 150 feet from the shoreline to 5 miles away. They reported results from the long-range testing from 2010 through 2022, demonstrating that the conditions for metal protection varied with the seasons, were much higher near the water than they were further away, and providing a baseline data for prediction of conditions and corrosion lifetimes elsewhere.

Summary: NASA made significant contributions to the development of a product that has generated a minimum of 50 x $10B annually = $500B of business since its inception!

Thanks, NASA!

GROOVED PAVEMENT

Automakers discovered very early on the importance of good tires and good pavement in preventing accidents, especially in wet weather. A phenomenon known as "hydroplaning," where water became trapped beneath the tire and road, caused skidding and loss of control. One solution was to create a tire tread footprint with grooves in it, allowing otherwise trapped water to move into the grooves rather than remain to lubricate the tire/pavement interface. After WWII, the growth of highways and the resulting increase in speeds on their smooth surfaces made the problem more acute. Merely creating a treaded tire was no longer enough.

The U.S. Department of Transportation got involved and began funding local research into the problem. Tests were conducted in Virginia, Texas, and California. The UK was interested in the problem, too, and was conducting similar research. Scientists realized that the concept of grooved tire tread channels giving water a chance to escape from between road and tire applied to the road, too. Why not try grooving the road surface, especially on smooth roads with curves, as an additional way to avoid hydroplane skids?!

The California Highway Department began aggressively researching grooved pavement, and issued a report in 1969 under the auspices of the Academy's Transportation Research Board, and road grooving started to become a tactic in making rain-slicked concrete highways' "Deadman Curves" less deadly.

Meanwhile, NASA's aeronautics half was starting to deal with the same issue. While few runways have curves and hills, they do have a length requirement that was growing problematically as aircraft became heavier and faster. Hydroplaning could cause airplanes to slide off the end of a runway. The ongoing Space Shuttle program was concerned, too; the Shuttle was heavy and would land at high speed – not a problem at Edwards, but potentially a big problem landing back at KSC. They hit the problem two ways, by researching the optimum groove size, shape, and spacing for aircraft runways, and by researching different tire compositions to ascertain the optimum material for aircraft/Shuttle tires.

It is difficult to acquire good statistics on events that did not happen, but there is no question that highway/runway grooving has prevented many accidents and saved many lives!

Personally, I am sensitive to this particular situation. My foe was an icy runway, not one with hydroplane conditions, but the problem was the same, a commercial airliner skidding out of control. I was on a late flight from Minneapolis to Grand Forks, North Dakota in February more than a few years back. Oddly, I had started out in the Mojave Desert that morning in short-sleeved shirt weather, but the upper Midwest was in the grip of a wintertime cold wave. The Minneapolis to Grand Forks was the last incoming flight that Sunday evening, and Northwest was motivated to get us home. The Grand Forks airport was contacted regarding conditions, and Northwest was told by the airport manager that the runways were clear and were ice-free.

The University of North Dakota's hockey team dominated the NCAA that year, but they never once skated on ice as smooth and slick as that poor Northwest pilot faced. We were in a DC-9, a workhorse mid-range hauler. The Grand Forks airport runway was just long enough to accommodate it, with a little bit to spare. I was watching out the window as we approached and saw that we were about to land "long."

The pilot was in a real jam. He knew he had to stop quickly, and was prepared with thrust reversers and brakes. Upon touchdown, the engines revved up as the thrust reversers deployed.

Then the nose of the aircraft began a sick swing to the left. The pilot firewalled the throttles; I have never heard a commercial aircraft's engines scream so. The pilot gamely tried to jockey the reversers to keep the plane on the runway, but to no avail. We didn't even start to decelerate, and after the nose had swung some 135°, we blasted through a huge pile of snow along the runway sideways. One guy did a “yee haw” during the spin (guess who). Nobody else made a sound as we stopped, feeling around to make sure they were OK. After thirty seconds or so, the call came to evacuate the aircraft. One flight attendant headed aft to open the tail door, but it was jammed by the snowbank. So it was out the windows we went. There was no panic, and folks began climbing out of the plane, onto the wing, then into the snow.

My seatmate on that flight was a tough farm widow, some 80 years old. Without a complaint, she followed me to the window hatch. It was easy getting out, and I paused beneath the edge of the wing to help folks with the short drop to the snow. Most had gone out already, and I was able to help the widow from the wing through the snow to the icy runway.

So far, nobody had been hurt, or even shook up much. The night was very cold, and our coats were still on the plane. Our adrenaline level was astronomical, and nobody really noticed the cold as we trudge/skated to the four-gate terminal a quarter-mile away. Several slipped and fell, getting the only injuries of the incident, minor cuts and bruises. The widow lady made it in without problem, what a trooper! We were the last two to come in, and my wife was greatly relieved to see me. Once everyone was safe, emotions took over for some, but everybody had done the right and proper thing throughout the ordeal.

I expected a phalanx of taxis, bearing lawyers, to be arriving any moment, but no. Northwest was determined to not have a morning photo taken of their plane sideways in a snowbank, and yanked it out with heavy equipment – they’d have ripped the tail off in the effort if they had to.

The airport manager got fired before morning, our bags were returned three days later, and we received a voucher for $75 from Northwest for the inconvenience.

Thank goodness that the DC-9 was a very strong aircraft. Had the starboard main landing gear collapsed when it hit that snowbank sideways, the engine would have likely sheared off and caused a bad fire. Instead, I’m here to tell the tale. I hope you will forgive me for saying that anything that helps prevent runway skidding is OK in my book!

[I wrote the paragraphs above before the airplane fire at Denver International Airport that required passengers to exit the window onto the wing!]

THE ALASKA PIPELINE

Oil companies were searching the world for drillable petroleum deposits after WWII. Many of the readily-accessible oil fields, such as those in Texas and California, had been exploited fully and would not produce much after the 1960’s. Further, environmental and tourism interests were against oil production in sensitive areas, a fear justified by the terrible oil spill off Santa Barbara in early 1969, where an 800 square-mile oil slick damaged pristine marine habitats and fouled heavily-visited beaches.

Prospectors had become much more aggressive in their search, looking in progressively-more remote regions. One such was the Alaskan North Slope on the Arctic Ocean, where a huge oilfield was discovered. It contained billions of barrels of petroleum, in an area where interference with tourists and environmentalists would be minimal.

There was just one problem: Getting the oil from the northern coast of Alaska to refineries and markets.

Oil seeps had shown the potential for oil production on the North Slope as early as 1900, but the harsh climate and primitive drilling technology shelved further exploration. Geologists from the Atlantic Richfield Company and Humble Oil drilled two-mile deep test holes and discovered oil at Prudhoe Bay on March 13, 1968.

> "The discovery of oil on the North Slope was a game-changer for Alaska and the United States. The oil reserves in the area were estimated to be massive, and the potential for profits was enormous. The State of Alaska quickly became a major player in the oil industry, and the revenue generated by oil production helped to fuel the state's economy for decades.
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> "In addition to the economic benefits, the discovery of oil on the North Slope also had political and strategic implications. With the United States becoming increasingly dependent on foreign oil, the discovery of a major oil reserve within the country's borders was seen as a major victory for energy independence. It also helped to strengthen the United States' position in the Cold War, as the country's ability to produce its own oil gave it a greater degree of strategic flexibility.
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> "The discovery of oil on Alaska's North Slope on March 13, 1968 was a momentous event that changed the course of Alaska's history and had far-reaching implications for the United States. Today, the legacy of that discovery continues, as Alaska remains a significant producer of oil and a major player in the energy industry." Source: https://akoghs.org/march-13-1968-oil-discovered-on-alaskas-north-slope.

But to make all this happen, a way of getting the oil to market had to be devised. The only practical means was to construct a pipeline from Prudhoe Bay to the Pacific port town of Valdez, from which it could be shipped by tanker to refineries and users. Significant financial, environmental, political, and engineering obstacles would have to be overcome.

The oil companies with interests at Prudhoe Bay formed the Alyeska Pipeline Service Company and devised a plan for construction, operation, and maintenance of the Trans-Alaska Pipeline System (TAPS). Political opposition was intense; environmentalists were rightfully concerned about oil spills anywhere in the system, potential for earthquake damage, effect on migration routes, and other issues. TAPS required Senate approval, which was obtained in July, 1973 when Vice President Agnew broke a tie to pass the Trans-Alaska Pipeline Authorization Act.

TAPS was an immense project. The pipeline had to be 800 miles long and would end up costing $8B to build. Pumping stations, loading facilities, and storage tankage would have to be built. Two mountain ranges would have to be crossed. Over the course of construction, 77,000 workers would be building the line, requiring huge amounts of logistical support. But the entire project hinged on one ominous problem.

The climate!

Flashback to WWII: The military wanted to beef up defenses in Alaska to counter an invasion threat from Japan. Sounds wild today, but the Japanese did seize two of the Aleutian Islands and did threaten ports like Dutch Harbor. The answer was to build bases in Alaska, which the military moved quickly to do. Getting construction supplies and military equipment to coastal Alaska was tough enough, getting material to Fairbanks and other locations in the Alaskan interior was tougher. The solution: Building the Alaska-Canada (AlCan) Highway and move materials by truck. Construction of the AlCan demonstrated that building atop ground in which the groundwater would seasonally freeze and thaw posed horrendous engineering problems.

A grizzled old-time farmer in New England, faced with the tough chore of harvesting rocks from their fields every spring could tell you all about how rocks get pushed upward when groundwater freezes beneath them. And you don't have to be a *Gold Rush* fan to know that when frozen ground melts, it loses most of its bearing strength. Heated buildings atop frozen ground might last a winter or two before they sink into the ground. Other engineering in cold regions problems exist.

[NOTE: There is a difference between "permafrost" and "frozen ground." The former is any ground, with or without ground water, that remains at below-freezing temperatures year-round. Frozen ground has water ice in the interstices of the particulate material making up the ground.]

The oil flowing through the TAPS would be warmed by friction. If the pipeline were buried or just lay atop the ground, the heat from the oil would melt the frozen ground below, and the resulting subsidence would damage the pipeline, incurring impossible maintenance costs. If the pipeline was raised on stilts, that would help, but the stilts would get warm enough to melt the ground ice below them and collapse. If the pipeline supports were buried deeply into the ground, seasonal ice formation would heave them out of the ground like the rocks in the New England farmer's fields, buckling the pipeline.

What to do, what to do? Why, call NASA, of course!

NASA engineers had wrestled with temperature management issues on satellites and spacecraft, especially those parts that were exposed to constant sunlight. Sometimes capsules could be rotated as if on a spit, to even out solar heating, but that was not always practical and some components, especially electronics, had to be cooled. Power requirements were an issue, too.

The solution NASA devised was nothing short of ingenious. It could provide cooling, using a system that required no power, had no moving parts, and needed no maintenance!

It is called a "heat pipe."

A heat pipe is a tube closed at both ends, containing a volatile liquid. One end of the tube is in a warm location to be cooled, the other is in a cool location, where the heat would be dumped. The liquid composition is chosen such that it would vaporize at the warm end, removing heat from that location in the process, and dump that heat in the cool end when it condenses back into a liquid, where it doesn't cause a problem.

Alyeska engineers designed a system to elevate the pipeline in areas where it couldn't lie on or below the ground, where two supports containing heat pipes were driven deep into the permafrost, from which a supporting platform was slung between them that would allow the pipeline to move laterally as outside temperatures changed (see picture and diagram below). The heat pipes were partially filled with anhydrous ammonia (NH3). If the heat conducted down the heat pipe became high enough, it would vaporize the NH3, lowering the temperature of the remaining fluid to the point where it couldn't melt any water present as ground ice. The vapor would rise to the top of the heat pipe to a radiator that would help the heat dissipate to the air above, where the ammonia vapor would condense and drain back down the pipe, completing the continuous cycle.

The heat pipe system would keep the support pylons anchored in the permafrost zone, but the pipeline itself was subject to thermal expansion and contraction, which could cause the pipeline to develop leaks over time, perhaps even rupture. The solution of that problem was to lay it atop the platform attached between the heat pipe support and to also build the pipeline with a zig-zag that could flex to accommodate stresses without breaking (see photograph below).

A total of 70,000 workers would be involved in building the TAPS during the period 1969-1977, with a peak employment of 28,000 in 1975. Construction of the pipeline itself began on March 27, 1975 and would be completed on May 31, 1977.

Several billion barrels of oil have been delivered though the pipeline to date. Initial daily rates jumped to 1.5 million barrels per day by 1980, then gradually increased to 2 million barrels per day by 1988. The Prudhoe Bay oil field is not infinite, and the daily transport rate has been steadily declining since 1988 and is now well below 500,000 barrels per day.

The pipeline itself has had relatively small environmental impact. The only serious incident to date was the grounding of the tanker *Exxon Valdez* as it left the port of Valdez on March 23, 1989, causing a serious oil spill and considerable local damage, especially to the fishing industry in Prince William Sound. Tankers had plied that route successfully ~8700 times, but complacency had set in and carelessness (drunkenness?) led to the grounding.

REFERENCES

NASA's *Spinoff 1976*: https://spinoff.nasa.gov/back_issues_archives/1976.pdf. The blurb about paint is on text page 21 (the pages of the text is not the same as the pages numbering of the pdf); the blurb about grooved pavement is on text page 28-29; and the Alaska Pipeline blurb is on text page 74-75

Anti-Corrosion Paint

KSC Corrosion Engineering Laboratory: https://public.ksc.nasa.gov/corrosion

PowerPoint for presentation at the 2023 DoD Corrosion Prevention Technology and Innovation Symposium: https://public.ksc.nasa.gov/corrosion/wp-content/uploads/sites/19/2023/07/DOD-AUG23-18646-Presentation.pptx

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Grooved Pavement

Beaton, John, Ernest Zube, and John Skog, 1969, Reduction of Accidents by Pavement Grooving, California Division of Highways (research project funded by the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads): https://onlinepubs.trb.org/Onlinepubs/sr/sr101/101-011.pdf

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Alaska Pipeline

Discovery of oil at Prudhoe Bay: https://www.pbs.org/wgbh/americanexperience/features/pipeline-discovery-oil-north-slope

Alaska Pipeline History: https://aoghs.org/transportation/trans-alaska-pipeline

NASA PowerPoint about Heat Pipes: here and here

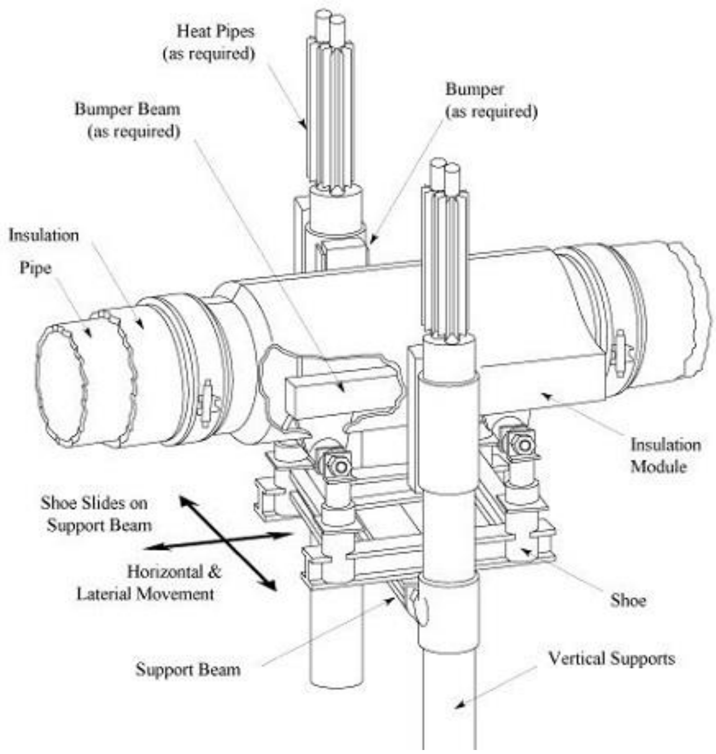
ASCE Library entry: https://ascelibrary.org/doi/10.1061/9780784483589.031

The Heat Pipe system used in the Alaska Pipeline was a 1990 inductee in the U.S. Space Foundation's Hall of Fame (for technologies developed first for use in Space exploration), see: https://www.spacefoundation.org/space_technology_hal/heat-pipe-systems

NASA Short Course on Heat Pipes: file:///C:/Users/dr_pa/Dropbox/Downloads/HP%20Course.pdf

EPA *Exxon Valdez* Spill Response: https://www.epa.gov/emergency-response/exxon-valdez-spill-profile

Exxon Valdez Oil Spill Trustee Council: https://evostc.state.ak.us/oil-spill-facts/details-about-the-accident



Top: A view of the Alaska Pipeline showing zig-zags that allow for thermal changes.
Bottom: A diagram of the ingenious heat-pipe system that keeps pipeline supports stable.
Source**:** https://aoghs.org/wp-content/uploads/2011/03/March-27-AlaskanPipeline-AOGHS.jpg

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