

# NAMMO INSIGHTS MAGAZINE

2022

PERSPECTIVES AND INSIGHTS FROM ONE OF THE WORLD'S LEADING  
MANUFACTURERS OF SPECIALTY AMMUNITION AND ROCKET MOTORS

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**Nammo**  
SECURING THE FUTURE

U.S. Marine Corps artillery fires at a night live-fire exercise. Photo by Staff Sgt. Donald Holbert / 11th Marine Expeditionary Unit

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# SECURING THE FUTURE

Western democracies are today facing challenges not seen in a generation, or even since the end of the second World War. At the time of writing, Russia has attacked Ukraine. Large-scale warfare between major powers, almost unthinkable not that many years ago, is once again a sad fact.

It is also a reminder of why we are here: Nammo's vision of "securing the future" was never more relevant. Both as a company and as part of the industry our role is to help NATO members and other allies in their most important job: Securing democracy, independence and freedom.

The near future will likely be crucial. We need prove ourselves – both in the traditional areas; delivering quality ammunition, rocket motors and weapons. We need to ramp up production to meet increased demand. And we need to continue to be a robust partner for governments with which we have security of supply agreements.

We must also keep thinking about the long term. That means a continued strong emphasis on R&D, developing new technology and building a company with a culture of competence and innovation.

I believe Nammo's ramjet rocket motor is one such key concept that will take us forward. Ongoing events just underline the importance ahead of long range precision fire. In an environment where the political and military situation can change rapidly, our commitment to NATO security stands firm. An important job requires the right equipment, and we will provide our allies with the very best to support the troops.

Nammo CEO Morten Brandtzæg.  
Photo: Nammo



# THE SMALL DETAIL THAT DOUBLES THE RANGE

On the battlefield, artillery range and firing power is crucial to overpower the enemy. Artillery is all about delivering massive fires – and preferably having more range than an adversary.



World War 1-era artillery typically had a reach of just over 20 kilometers. For almost a hundred years after that, ranges did not really increase. But the situation is finally changing. Nammo is working on several technologies that enable current 155 mm heavy artillery systems to hit targets at previously unheard-of distances.

Two related concepts are base bleed and rocket assist. The former is already qualified and in use, the latter is in development. If one is to understand how they work, reducing drag and adding thrust are central concepts.

"It is all about decreasing the projectile's drag", explains Vice President Large Caliber Systems at Nammo, Audun Dotseth. Drag is the force that acts upon

the projectile opposite the direction of motion, increasing proportionally to the velocity. Reducing drag can be a key factor to increase the range of a projectile.

### **TWO MAIN TECHNOLOGIES**

"At present, there are two main technologies to reduce drag, base bleed and rocket assist", says Dotseth. "Base bleed increases range from approximately 30 kilometers to 40 kilometers, or by 25 percent. Rocket assist, while still in development, promises a further increase up to 70-80 kilometers", he says.

Simply put, base bleed decreases drag by attaching a small package of propellant to the base of the shell. The



small charges are ignited by the gases that develop during the firing of the shell and burn for approximately thirty seconds. The resulting exhaust flame from the base bleed grains help reduce drag significantly.

### KILLS TURBULENCE

"What is important to understand is that the base bleed component does not deliver any propulsion as such. Rather, it acts by reducing turbulence at the base of the projectile, thereby reducing drag", explains Dotseth. "The result is much longer firing range, without any compromise to the firing power of the shell", he adds. "There is of course a slight cost, but it is outweighed by the significant increase in range, which can be a massive advantage."

Nammo artillery shells come with interchangeable base bleed or hollow base unit, allowing for great flexibility. When more range is needed, the base bleed unit is simply attached to the shell.

### EVEN LONGER RANGE WITH RAP

The Rocket-assisted Projectile (RAP), on the other hand, is just that – equipping artillery shells with a rocket unit which adds some propulsion. The ability to

be fired from existing systems is a key advantage, and Nammo is expecting ranges up to 80 kilometers.

"This is rather well-known technology, but still not widely used", says Dotseth. One of the reasons for this might be

**the significant increase in range can be a massive advantage**

that RAP comes at a cost to the shell's firing power, as the rocket propulsion unit takes up space and weight. Therefore, the shells carry less explosives.

"This is a tradeoff, but we believe the extra range is a great benefit, outweighing the disadvantages."

The grains in a RAP unit are three times the size of base bleed-grains. The unit has to withstand a massive 15 000 Gs generated as the projectile accelerates from 0 to 950 m/s in the span of twenty milliseconds.

### NEW POSSIBILITIES

"This huge increase in range is beneficial for two mainly reasons, both to be able to take out targets outside of the range of ordinary artillery and of course to

protect your own forces. This gives a huge advantage in flexibility and protection", says Dotseth.

Nammo is currently doing extensive research into RAP. When the technology is ready – likely in a few years' time – the company will probably look into adding guidance units as well.

"With RAP projectiles having such a long and high trajectory, this will greatly increase the accuracy of this type of ammunition."

Dotseth adds: "Most of the conflicts we have seen for the last twenty to thirty years, can be categorized as low intensity conflicts. There was a big emphasis on counter insurgency activity. But in recent years, the focus on artillery is back. It's still the king of battle and never lost its importance. Nammo is committed to support NATO allies with the best technology, and we are currently involved in several projects to take this technology even farther."



**A rocket-assisted projectile flies through the air at Nammo's Test Center. The added thrust enables this artillery concept to have a reach of approximately 70–80 km. Photo: Nammo**



A ramjet projectile pictured during testing. Photo: Nammo

## NAMMO AND BOEING COMPLETE ADVANCED RAMJET TESTING

### Paving the way for long distance flight tests.

After more than five years and hundreds of tests, the Nammo/Boeing ramjet powered artillery grenade has passed several critically important milestones. With the current levels of technical and technological progress, the company expects a transition to more advanced long distance flight testing within a few months.

“Our ramjet rocket motor is rapidly reaching a mature state. Several of the most important aspects, such as launch, motor ignition, fin opening, stable flight and not least the motor performance, have reached a state of reliably good performance. This was not an easy feat, especially considering the violent g-forces (15.000Gs) the projectile is subjected to during launch”, says Erland Ørbekk, Nammo’s VP Advanced Propulsion Technology.

Nammo has partnered with Boeing on a project that will deliver ramjet for 155mm artillery. With the current design, ramjet artillery can be fired from any 155mm howitzer. Nammo sees the technology as one of the most important and most promising in terms of technological advancement in the company’s history.

“The latest test have been extremely promising. For the first time, I think

we can start looking forward to a qualification process. We still need to complete long distance testing as well as implementing the guidance, but if all goes well qualification can start in 2023. Production would not be too far off after that”, says Nammo CEO Morten Brandtzæg.

During a January-March, 2022 test campaign, several important changes and revisions to the artillery projectile were tested for the first time. This included a new fin design, a new body design, as well as changes to the rocket motor setup. Considering these major changes, the ramjet-powered projectile still worked as expected.

“There were no surprises. The projectile did exactly what we had predicted in advance, and the motor performed according to our calculations. With all the changes we made before launch, I believe that is impressive. But it also shows we understand and control the technology. What we have now is a projectile that for the first time is tactically representative (on the propulsion side). By that I mean that it very closely resembles a final version, and works and performs similarly. We believe further major revisions to the propulsion unit are unlikely”, says Ørbekk.

“Projects like this one, the ramjet development, often can take more than

a decade. Problems or setbacks can occur, and redesigns are common. In this case however, I believe we are seeing much more rapid progress. We have had no major stumbling blocks, and for something as technologically complex as a ramjet engine, I believe that is extraordinary. I am attributing that to Nammo’s unique combination of rocket motor and ammunition expertise. In addition, having development, testing and production facilities all at the same location dramatically reduces the time to market”, says Nammo CEO Morten Brandtzæg.

While Nammo and Boeing will cooperate on some further short distance tests, the success of the January-March, 2022 campaign means that the next phase, long distance testing, is rapidly approaching. This will be a major milestone, and if successful, the last before the pre-production phase. Long distance firing means that ramjet-powered shells could fly well over 100 km.

The January tests were part of the Nammo-Boeing ramjet cooperation for 155 mm artillery, however Nammo also aims to work towards ramjet-powered missiles. Ramjet technology is expected to greatly increase artillery range on the battlefield. Air-to-air missiles could see ranges up to 500 km.

# 3-2-1-FIRE!

Preparing for an artillery test at Bradalsmyra, during the winter of 2022. Photo: Nammo

**Modern ammunition must meet very strict quality requirements. At the Nammo Test Center Bradalsmyra, more than 18 000 rounds of ammunition are fired and documented every year.**

Located at Bradalsmyra, some fifteen minutes' drive from the Nammo headquarter at Raufoss, the Test Center covers 1600 acres of land with 80 buildings on it – making it one of Europe's largest ammunition test facilities. Of course, the security is strict, and before entering the premises, all visitors are given a bright orange visitor's jacket – for visibility and at the same time providing some protection



Knut Johan Nybakke at the Nammo Test Center. Photo: Knut Jørgen Holby

against the icy wind that turns an otherwise sunny day in February into a rather chilly experience.

The first step of the day is a firing hut where red warning lights already blink fiercely. Knut Johan Nybakke, acting supervisor of the Test Center, acts as guide into the low building and gives a short tour of the premises. On the ground floor, two test cannons are bolted to the concrete floor, barrels pointing towards a concrete bunker at the bottom of the mountain slope some 200 meters away.

## FROM HAND WEAPONS TO ARTILLERY

"Here at Bradalsmyra, we carry out advanced tests of ammunition ranging from 5,56 to 155 mm in our 15 firing ranges", says Knut Johan Nybakke. "The equipment and facilities at Bradalsmyra allow for the precise measurement and

**Our engineers may complete a prototype before lunch and have it tested in the afternoon**

documentation of internal, external and terminal ballistics, and several super high-speed cameras are available to visually document the projectile's path."

Today, the ammunition to be tested is the 30 mm x 173 APFSDS-T, an armor piercing round with a tungsten penetrator. One floor above the cannons, we gather behind the windows facing the target, the count-down starts and we hear the gun go off. Fractions of a second later, the tungsten penetrator slams into the receiving area at the base of the mountain slope. "We do a range of measurements on the rounds fired", Nybakke explains. "Projectile speed, trajectory and fragmentation as well

as combustion pressure in the cannon are among the data we collect”, says Nybakke. “Essentially we can measure the firing sequence from start to finish.”

### WORLD'S LARGEST ELECTRO-MAGNETIC VIBRATION MACHINE

In addition to testing ammunition from the production line at Raufoss, the Test Center is also equipped to test rocket engines, both in motion on a rocket track and mounted in test benches. It also contains a highly sophisticated environmental testing facility, where ammunition can be tested for vibration, shock and climate.

“Our test facility meets international military and civilian testing requirements. Here it is possible to emulate a broad range of conditions, for example vibrations from cobblestones or other highly specific environments”, Nybakke explains. “Our equipment includes the LDS V994, which is the

world's largest electromagnetic vibrations machine and one of a handful worldwide certified to test energetic products at ambient and extreme temperatures.”

### A GREAT ASSET IN PRODUCT DEVELOPMENT

“While there are of course several test centers in Europe, Bradalsmyra is rather unique in one aspect”, explains Thorstein Korsvold, a member of the Nammo communications team.

“The line of communication from developing engineers at Nammo to the Test Center is very short. Our engineers may complete a prototype before lunch and have it tested in the afternoon. This is a significant advantage in our innovation processes, in addition to facilitate the continuous testing of products from Nammo's production lines. It is safe to say that Bradalsmyra is indispensable to our business”, he says.

### ATTENTION TO THE ENVIRONMENT

In line with Nammo's focus on environmental safety, the Test Center is under continuous monitoring by NIVA, the Norwegian Institute for Water Research, and all waste from the testing is being burned twice weekly to avoid any leftover debris polluting the area.

“Safety and environment are our main concerns. NIVA's reporting shows that there is minimal pollution from the Test Center. That is of key importance, as we adhere to the UN goals for sustainable development”, Korsvold says.

### THE HEAVY MACHINERY

On the way to the last stop on the tour, Nybakke points towards some old cars that are placed on the premises. “Those will be fired against later this week”, he says with a grin. “We need to be able to conduct testing against a wide range of targets.”

The long-range firing range is located at the outskirts of the compound. Here, two German built cannons in 120mm and 155 mm are mounted, providing the opportunity to test fire tank and artillery ammunition. During the tour the sun has risen and the view along the barrels, which can only be moved in the vertical dimension for safety, is magnificent.

“These artillery cannons have a range of up to several miles. When they are fired, it is hard not to notice”, Nybakke states with a smile.



A controlled explosion at the test center. Photo: Nammo



Test firing in the winter can be a cold, dark affair. But sometimes it's different. The combination of tracer rounds and Northern lights was surprisingly beautiful. Photo: Nammo

### DID YOU KNOW?

Established in 1919, Bradalsmyra has a long history as test facility for ammunition and propulsion systems. The site was developed in two phases in the 1950s and later upgraded to meet international requirements in the 1980s. Today, around 40 highly qualified personnel have their daily work at Bradalsmyra.



A bullet captured as it penetrates aluminum plates. Photo: Nammo

# THE SLOWEST MOTION POSSIBLE

Remember the famous scene in “Matrix” where Keanu Reeves dodges the bullets? That’s the kind of slow motion filmed routinely by engineer Alexander Kvale, at the Nammo Test Center.

Among the 40 or so highly skilled employees at Bradalsmyra Test Center is Alexander Kvale. The test engineer has had the job for 13 years, and he still needs to pinch himself in the arm now and then to realize that he does indeed have the best job in the world.

“Ever since I was a kid I have been interested in technology, and I am an avid fan of Mythbusters”, he tells us. “Here I get to do my own myth-busting every day, and I couldn’t imagine a better place to work”, he says.

## LOTS AND LOTS OF PICTURES

Kvale’s main area of expertise is ultra high-speed photography. And by ultra high-speed, we mean really, really high speed.

“At Bradalsmyra, we own six cameras capable of taking up to 2.1 million pictures per second. When interlaced, they can catch up to 4.2 million images per second”, he says.

Aerospace & Defense and combustion are indeed areas where there is a need for such extreme speeds, although using the cameras to their full capacity is rather rare. Speeds of some 100.000 high resolution images per second are more usual.

**At Bradalsmyra we own six cameras capable of taking up to 2.1 million pictures per second**

be able to count the shrapnel, the disintegration pattern and rate. It still fascinates me to see the physical world when time is stretched out like that. The cameras catch everything.”

“We typically film test firings, and the equipment is able to follow the projectile from it leaves the muzzle of the weapon until it hits the designated target”, Kvale explains. “We also film all sorts of explosions to

To be able to follow projectiles travelling at hypersonic speeds, one needs more than a quick flick of the wrist. Bradalsmyra is equipped with a NOK 2.5 million Flight tracker that moves the cameras in sync with the projectiles.

“The sight of a bullet in its trajectory, seemingly still in the air, is almost majestic”, Kvale says.

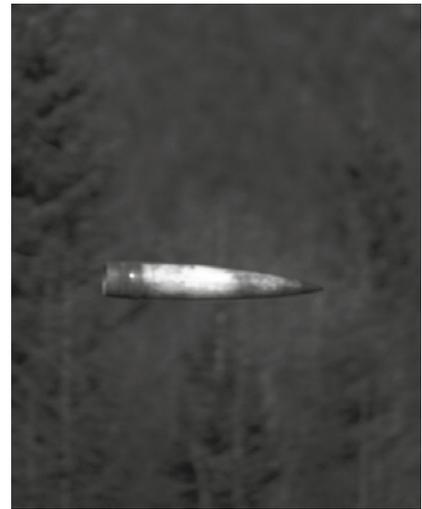
## MONTHS OF PLANNING

The planning of an experiment may take months, and some cost millions. Kvale is central to the planning and set-up of the right equipment.

“Much of the proficiency at designing ultra-high speed photography experiments is located here at Bradalsmyra. Of 15 cameras in Norway, we own six”, says Kvale. “In some periods the testing is intense, with several experiments done every day. That takes several months to plan.”



A cannon fires at Bradalsmyra. Testing is an essential part of both quality control and product development. Photo: Nammo



An artillery projectile captured by a high speed camera. Even though these cameras can capture up to 4.2 million frames per second, often 10.000 is more than enough. Photo: Nammo

Technology-wise, suffice it to say that the cameras utilize large numbers of image sensors, one sensor feeding many others. Another system divides the sensor into smaller parts, capturing many images onto one chip.

"It is a bit advanced and difficult to explain", says Kvale. "But it surely works."

What is also intense, is the staggering amount of data captured. Today, the cameras at Bradalsmyra produce 8 terabytes per year. That number keeps going up.

"Typically, the amount increases at a rate of 2 terabytes per year", Kvale explains.

### FINDING THE ERROR

The use of ultra high-speed cameras is a crucial part of the testing taking place at Bradalsmyra, and when something doesn't go according to plan, the images are essential in identifying the failure.

"It is really one of the most satisfying parts of the job, to be able to help find out what has gone wrong. I have even had to cut the image sensors out of the cameras to analyse faulty explosions. It is satisfying and essential to ensure the safety of our products", Kvale says.

Besides being responsible for the high-speed photography, Kvale also does some product development. Among other things, he is experimenting with drone mounted M72's, to expand the famous rocket launcher's scope of application.

"What I really love about this job, besides how important and interesting it is, is that no days are alike. Here we get to work with the newest and most advanced equipment available, and there is room to develop one's own ideas. No wonder I sometimes don't think of it as a job."



Test engineer Alexander Kvale is one of Nammo's expert photographers. Here pictured while operating a high speed camera. Instead of moving lens elements, a normal part of video recording, this camera moves small mirrors. At extreme speeds, the lens elements are just too heavy. Photo: Nammo

## M72

# THE MIGHTY JACK OF ALL TRADES



**The M72 has been around for 60 years. Yet, it remains as relevant as ever. The weapon's ability to penetrate beyond an astonishing 450mm of reinforced steel, counter drones, and practically fire around corners are some of the reasons.**

First introduced in 1963, the M72 LAW (Light Anti-tank Weapon) combined a couple of important properties: It was low weight, easy to carry, easy to use and powerful against

armored targets. It really had two predecessors: One was the German Panzerfaust, the other was the American Bazooka. Both were capable in their own right but had significant drawbacks:

### **WORLD WAR 2 PREDECESSORS**

The Panzerfaust had a big warhead that could smash a 2.75 inch (7 cm) entry hole in a tank, as well as spreading deadly burns and shrapnel on the inside. Its main drawback



A Marine fires an M72 during an exercise in Jordan. U.S. Marine Corps Photo by Cpl. James Stanfield



U.S. soldier holding an M1 "Bazooka", 1943. Photo: United States Library of Congress

was the very short 30 m range and the considerable in-combat danger to the user. The Bazooka was conceptually quite different. As the first rocket-propelled grenade launcher, it gave the advantage of a much longer range, but the initial version only had one tenth of the explosive power of the Panzerfaust. An entry hole in a tank would typically only be 0.5 inches (1.3 cm). In addition, the large and cumbersome weapon needed a two man crew to operate.



The M72 FFE (Fire From Enclosure) is a new M72 variant. It has no backblast, and can be used in confined spaces. Photo: Nammo



Finnish soldiers armed with Panzerfausts fighting against Russian forces during the Battle of Tali-Ihantala, Finland, 1944. Photo: Finnish Photograph Wartime Archive, SA-kuva



A U.S. Army Special Forces soldier fires an M72 during a training event. U.S. Air Force photo by Staff Sgt. Joel Pfister

"After World War 2, the US Army looked for a bazooka replacement. They wanted something better – preferably a smaller weapon with more power. A difficult task, but some competent engineers were able to come up with a concept that seemed to work very well", says Quoc Bao Diep, Nammo's Vice President LCS (Large Caliber Systems).

### COMBINING AND IMPROVING

The M72 basically combined the Panzerfaust and the bazooka. A 66 mm launcher tube gave room for a rocket with a decently sized warhead, and the range was much better than the original Panzerfaust. Armor penetration was more than sufficient, and the weapon could be operated by a single person without much training. The weapon was also light and one person could carry several M72's – a huge leap forward from the two-man bazooka teams.

Six decades later, more than a million have been made and the

**One variant of the M72, the M72 EC, has been tested to penetrate more than 450 mm**

M72 remains in service in more than 30 countries. Quoc Bao Diep says the basic concept is still the same.

Sure; the M72 has changed, but the original concept is still there, and it is still relevant in the battlefield. The weapon is an easy-to-use system effective against multiple target types, including armored ones.

### THE SHAPED CHARGE

At the very core of the M72 lies the so-called shaped charge. It is this that gives the warhead its penetrative ability. When a hollow or void cut is made on the surface of an explosive, the blast effect will focus there. Also, a metal liner here can transform into a liquid form, further focusing the blast and enhancing the penetration.

"In the M72, we have optimized this effect with the most powerful explosive available. We combine it with a wave shaper that guides the shock wave. We use a copper cone, and this becomes a copper jet that goes into the target at a speed of more than 8500 m/s. The kinetic energy attained is enormous, and can penetrate deep into any armor."

"Deep into any armor" is no exaggeration. One variant of the M72, the M72 EC, has been tested to penetrate more than 450mm. And that is the so-called "RHA" variant; Rolled Homogenous Steel.

### ENHANCING AND DIVERSIFYING

Over time, the M72 has been improved, and more variants have been added.

*What have been the most important changes?*

"With the M72 A4, Nammo introduced a bigger rocket motor. Later, the EC version got a new launcher and a new fuze. The system definitely became more safe, easier to use and with a longer range as well", says Diep.

The M72 EC follows in the footsteps of its predecessors, but as the M72 system has matured, new variants with different properties have come along. One is known as the "ASM" (Anti Structure Munition). This variant has a different warhead that works better against lightly fortified structures or buildings. Another is the "FFE" (Fire From Enclosure) which eliminates the backblast by using a counter mass.



Nammo is working on a drone-mounted M72 concept as well. In 2022, testing and development are well underway. Photo: Nammo

"We also expect a version with airburst to be qualified soon. This will be ideal against targets such as drones, for indirect fire, or for anti-personnel use", says Diep.

### LOITERING AND DRONE-MOUNTED

Nammo's work to improve the M72, and add versions, continues. A drone-mounted version is in development, and the company is exploring loitering weapon possibilities as well.

"What started as a single shoulder fired weapon, today has evolved into multiple variants meant for different scenarios. But we still believe in the core concept: The M72 is lightweight, easy to use, and very powerful. I believe it will be with us for many more decades", concludes Diep.



Quoc Bao Diep, Nammo's Vice President LCS, standing next to an in-development M72 loitering weapons concept. Photo: Nammo

# ROCKET MAN



How did a small Norwegian company become one of NATO's most important rocket motor producers? We asked Frank Møller, one of Nammo's most central figures in the field for almost four decades.

Frank Møller came to Raufoss in 1984. Before that, he had been a chief engineer on a Royal Norwegian Navy submarine. Looking back to his first years at the Nammo Test Center, he feels the advances in rocket motor technology have been great. But things have not really slowed down since those early days. Frank is still part of a development team, and their work could result in new technology with a potential to revolutionize missiles.

"I like to joke that we make "fire-and-forget missiles", while the HR department could do "hire-and-forget", Frank Møller says, smilingly.

*Hire and forget, indeed! You do realize you've stayed almost 40 years in the same place?*

"I planned on staying for two or three years, but I am still here. Most people who come here like the company, and tend to take root. So did I. I like my colleagues, and in some ways the work is more exciting than before", says the veteran.

## FROM AMMUNITION TO EARLY ROCKETS

Norway's rocket motor production has its roots in the years just after World War 2. The weapon system "Terne" was at that time developed in cooperation between FFI (the Norwegian military research institute) and U.S. Navy. Terne was an anti-submarine system in use from the late 1950s until the early 1970s, based on rocket propelled sinking mines. It became the foundation for further Norwegian technological development in the propulsion field. The Raufoss ammunition factory became the hub for this work.

With all its technological know-how in the propulsion field, Nammo soon

became involved in the Sidewinder AIM-9 air to air missile. If we count all the various versions of the Sidewinder, no other system has been produced in larger numbers. A key production technique was the extrusion of the propellant powder. The experience with both missiles and production techniques lay the foundation for the many other systems Nammo later got involved in, like AMRAAM or EXOCET. When Nammo was established in 1998 through the consolidation of Nordic defense companies, Raufoss was still the hub for rocket motors.



## SIMPLE CONSTRUCTIONS - AT LEAST IN PRINCIPLE

After a year and a half at the Test Center, a couple of years doing security analysis and statistics, Møller changed to rocket motor development. There, he rose through the ranks and was selected to head the development programs. One of the projects he was responsible for, was the propulsion system for the Penguin mk 2 mod 7 naval missile (launched from helicopters). And in the years after that, many other rocket motor systems, including rocket systems for the European Space Agency (ESA) and their Ariane program. Among his latest endeavours on the military side is work for the NATO-led ESSM missile program.

"You know, rocket motors are really very simple constructions, at least in principle", Møller says.

"Just try to visualize a balloon which you've blown up and then let go. That's a rocket motor right there. It becomes a tube with an opening on one end, and there's energy in the form of pressure in it."

## EXTREME STRESS

While a balloon can be a decent illustration of how a rocket motor works, it is not exactly ready to be used in combat at a few times the speed of sound.

A modern rocket motor must endure extreme stress: Not only must it withstand conditions varying from warm summer temperatures on the ground to 50

**You know, rocket motors are really very simple constructions**

the rocket motor fuel is ignited, those can reach 2-3000 degrees. Strong G-forces are normal as well, and on

degrees Celsius below zero when it's mounted underneath a plane wing. It will also be subjected to the high burn temperatures when

top of that, a missile must be able to maneuver.

"In a rocket motor, the component materials are pushed to the limits. From an engineering standpoint, the materials and the propellant take centre stage", Møller says.

## NEW PROPELLANT TECHNOLOGY

In the late 1970s, various NATO Air Forces acquired the new F-16 fighter jet. The new plane itself was a significant upgrade, but also brought technological change to many of its subsystems. The missiles were affected, and where older rocket motors had been powder driven, the new generation used a cast composite fuel type.

The new rocket fuel was more demanding to work with, since even a miniscule bubble or irregularity could lead to major safety issues such as explosion risk.

"At the time, this was a completely new technology. But as time passed and our experience with it increased, it has been gradually improved. Today, cast composite fuel is our workhorse solution for both missiles and space rockets", Møller says.

One problem is that most such fuel types contain significant amounts of ammonium perchlorate. When the rocket fuel burns, it releases hydrochloric acid.



"Hydrochloric acid is a less than ideal waste product, as it is both corrosive and toxic. In a time where we see increased activity in both the military missile sector and the space sector, we need to find better solutions", Møller says.

### VERY OLD ROCKET MOTORS FOR THE FUTURE

Luckily, Frank Møller is part of a Nammo team working on something that might be just that – a better solution. The concept – known as ramjet – is about as old as it gets in the aviation world. French engineer René Lorin filed a patent for a subsonic design back in 1908. Another french aviation engineer, Rene Leduc, continued his research and eventually built several ramjet-powered planes (known as the Leduc planes). These would fly test flights in the late 1940s and throughout the 1950s. Several aspects of these ramjet planes were very promising. For example the Leduc 0.22 had an astonishing climb rate: 39.000 ft per minute. No jet planes in existence at the time could compete. (the contemporary US F-100 jet fighter plane could climb at 16.400 ft per minute). Even today, the Leduc would climb only slightly slower than, say, an F-16. But even with these promising prototypes, more conventional planes would be chosen by militaries around the world.

– In a ramjet, the oxygen that is needed

**Our testing so far indicates ramjets can massively outperform conventional rocket motors**

for combustion is taken from the air. It is driven through air ducts at high speeds, compressed, heated, and becomes part of the combustion process, Møller explains.

The ramjet concept is simple, and maybe obvious in some ways. And building a working ramjet? Definitely doable, even 70 years ago. But getting it to work well? Almost impossible. Conventional rocket motors or jet engines were just easier to make.

Building a working ramjet? Definitely doable, even 70 years ago. But getting it to work well? Almost impossible.

Efficiency has long been the key factor. Until now, getting to that peak potential is a feat no-one has achieved. And then there are the practical questions: How do you make an efficient ramjet plane if the motor needs very high speeds to even start operating? How do you land such a plane safely?

On the missile side the ramjet troubles were less pronounced. Successful 1950s and 1960s designs such as the UK Bloodhound and Sea Dart missiles or the RIM-8 Talos missiles all worked well. But so did conventional designs.

"Cast composite rocket fuel became the workhorse technology powering both missiles and spacecraft. Solid fuel ramjets were at times something exotic, half-forgotten. So were liquid fuel Ramjets, only even more complex and expensive. Many engineers probably saw the potential, but still ended up using more standard concepts", Møller says.

### MASSIVE PERFORMANCE INCREASES

However Møller feels that this type of propulsion may have plateaued now – with further major efficiency gains unlikely.

"As I see it, conventional rocket motors have two problems. Firstly, they release hydrochloric acid as part of the combustion. Secondly, getting much more performance from them seems unlikely", Møller explains.

Ramjet technology may, on the other hand, still offer very substantial performance increases.

"Our testing so far indicates ramjets can massively outperform conventional rocket motors. Additionally, missiles built around ramjets will be more maneuverable. And last but not least: no hydrochloric acid emissions", Møller says.

He also believes Nammo engineers are finally on the treshold of unlocking the true ramjet potential.

"The combustion has always been a problem. No-one was really able to control it well. But with new tools, we can do just that today. At around mach 3, we are seeing just the right pressure and temperatures. Armed with new analysis tools, we can also optimise any other aspect of the rocket motor."

As much as 80 % of current rocket fuel is oxidiser (solid oxygen). Just 20 % is actual fuel. With an optimal combustion process, one could remove the oxidiser entirely from ramjets.

"Obviously, if the amount of fuel is increased from 20 to 100 % – that's a win. How do you use all that extra propulsive energy? Range – much more range – could be one answer. I believe the ramjet is the rocket motor of the future. And it's not a far-into-the-future concept. We are going to demonstrate long range flight this year, in 2022", Frank Møller states.



A ramjet rocket motor pictured during a static test at the Nammo Test Center, Bradalsmyra. Photo: Nammo

## A NEW PARADIGM IN WARFARE

If ramjets are successful, what implications will we see on the battlefield? Møller believes artillery could see drastic changes. Gun-fired ramjet projectiles could massively extend artillery range – possibly well beyond 100 km. If combined with precision or guiding systems, some artillery projectiles could end up looking more like missiles.

Then again, if ramjet motors become widely used in missiles, they too might change. More range, higher altitudes and the ability to strike an opponent while out of his range are all likely.

"Ramjets can increase missile range by several times. In addition, I believe we'll see more maneuverable missiles. The tactical and strategic potential? It's hard to say, but it could be very significant. Maybe we'll see foundational changes to NATO and US air defense paradigms? In any case: The work on ramjets will come almost last in my career, but could still define it. During these decades,

we always thought we were really successful if we could improve a system by a few percentage points. Now we see a hundred times that. This is a once in a lifetime-thing, I believe", Frank Møller concludes.



"Terne" missiles are fired from a Norwegian frigate, date unknown. Photo: Norwegian Armed Forces



The French Leduc 0.20 was an experimental ramjet plane built in 1953. It was in some ways far ahead of its time. However it was not capable of take-off on its own, and had to be carried aloft and released. Photo: Wikimedia Commons



Ammunition cases on the ground. In the background, a burning ISIS vehicle. Photo: Camilla Brevik Hågensen / Norwegian Armed Forces

## HOW MP AMMUNITION STOPPED THE ISIS SUICIDE BOMBER

**Iraq 2017: An armored ISIS suicide truck packed to the brim with explosives speeds towards coalition forces. Norwegian commander Terje Bruøygaard watches as Iraqi and other coalition forces fire at it, without penetrating the armor. His unit, however, has something the others do not: Nammo's .50 cal multipurpose ammunition.**

Lieutenant Colonel Terje Bruøygaard – who led a group of Norwegian soldiers advising an Iraqi brigade – knew the situation was becoming critical. In less than a minute, the truck would drive right into hundreds of assembled soldiers and vehicles.

The main part of their column was Iraqi, but several smaller groups, mainly special forces from allied countries, accompanied them.

When the column first became aware of the ISIS suicide bomber speeding towards them, there was no immediate

sense of concern, Bruøygaard explains. It was still more than a kilometer away, which gave the coalition forces time to react.

Some of the soldiers had seen incidents like this before. Towards the end of 2017, Mosul had already fallen. Thousands of desperate ISIS fighters still held Anbar province in Iraq, as well as their capital, Raqqa. As the terrorist group neared their final defeat, they experimented more with suicide attacks.

The bomb trucks usually were stopped before they could harm their enemies.

But this one kept coming closer.

“We could see it was headed straight for our column. They had welded steel plates onto it. As improvised armor, it worked reasonably well. Some other soldiers in the column fired at the truck, but I don't think they penetrated the armor. I felt we were getting to a point where we needed to do something”, says Terje Bruøygaard.

### **ARMOR PENETRATING AMMUNITION**

One option was to call in air support. The truck would never withstand a direct hit from the air – or perhaps an



In 2019, Lieutenant Colonel Terje Bruøygaard was awarded the prestigious Norwegian War Medal for his actions.  
Photo: Torbjørn Kjosvold / Norwegian Armed Forces

anti-vehicle missile could be employed directly by the ground forces. But even with such systems at the ready, the window of opportunity was short.

Luckily, the Norwegians had something they could bring to bear almost instantly.

"We have access to special ammunition that is both armor piercing and incendiary. In this particular case, that was an ideal combination, and the ammunition was ready for use."

The MP ammunition was developed in Norway in the 1970s and was originally intended against Soviet trawlers. Norway feared that if the Soviets ever invaded, they could use the trawlers to transport troops into Norway, and at that time the Norwegians lacked weapons that would be effective against the thick trawler hulls.

Later, it turned out that the MP ammunition worked very well against other armored targets, especially those carrying flammable cargo.

The ISIS bomb truck speeding towards the soldiers on that day in 2017 definitely had that.

"I decided we had to fire at the truck. We never felt rushed or really threatened. Once we decided, training

just took over. We did what we had to do", Bruøygaard says.

**How often can you be part of something like this – liberating a country? For me personally, I think it was one of the most rewarding things in my life**

have carried around two hundred kilos of explosives. When we stopped it, it was only a few hundred meters from the rear elements of the column we wanted to protect, Bruøygaard explains – and adds: It was a really good feeling; to see that we could stop them."

#### **LIVES SAVED**

After the attack, soldiers from an unnamed allied special forces unit came up to the Norwegians, asking about their ammunition.

The Norwegians loaded their .50 cal MP ammunition, looked at the target through the Kongsberg weapon station mounted on their vehicles, aimed and fired. A moment later, they could see the result of the impact.

"We clearly hit it. We saw how it exploded and went up into flames.

We believe it could have carried around two hundred kilos of explosives. When we stopped it, it was only a few hundred meters from the rear elements of the column we wanted to protect, Bruøygaard explains – and adds: It was a really good feeling; to see that we could stop them."

"They were astonished by what we had done, and asked about our ammunition. They had probably used the same caliber, but a different type of projectile as they fired at the truck. Since they could not penetrate the armor, they would have liked to have the same ammo, I believe", Bruøygaard says.

Two years later, in May 2019, Terje Bruøygaard received the Norwegian War Medal ("Krigsmedaljen") for his efforts in the fight against ISIS. The incident where his soldiers possibly saved hundreds of lives by stopping the ISIS suicide truck was part of the reason.

"I feel that we have gotten a lot of recognition for what we did. And of course, there was never room for any doubt: ISIS is an evil organization. We had to stop them, we had to fight them", Bruøygaard says, and adds:

"How often can you be part of something like this – liberating a country? I think we're all proud of what we did in the fight against ISIS. And for me personally, I think it was one of the most rewarding things in my life."



# ARMOR PIERCING AMMUNITION – HOW DOES IT WORK?

**Armor piercing ammunition is all about the concentration of kinetic energy in the smallest possible area at impact. Product manager Jan Hasslid at Nammo explains how it works.**

"First of all, there are two main categories of armour piercing ammunitions", explains Hasslid. "There is the arrow type, which does not contain any explosives, but relies on a heavy metal core in the projectile to penetrate the armour. Then there is the type which relies on an explosive detonating on impact, forming a copper or tantalum penetrator, typically used in the field to stop armored vehicles like tanks", he says.

Hasslid compares the focusing of energy into a small area with sending light through a magnifying glass. The goal is to concentrate the energy into a very small point in the armor and deliver enough force to go through it. And rest assured, it is more complicated than it sounds.

#### **FOCUSING THE ENERGY**

"The projectile has typically travelled more than two kilometers before impact.

To be able to focus the energy properly, a deep understanding of ballistics, both the projectile's inner ballistic properties as well as transitional ballistics, what happens when the projectile meets the air, is essential. Here at Nammo, we do extremely extensive ballistic testing at our own testing field, Bradalsmyra", says Hasslid. "That also includes tailoring the ammunition to specific demands as to penetrating capabilities."

The goal, of course, is to create a stable

Marines fire a M240B machine gun during an exercise in Australia. U.S. Marine Corps photo by Cpl. Harrison Rakhshani



piercing ammunition is designed to be shot from stable cannons in the range of 30 mm to 120 mm – from a combat vehicle to a main battle tank cannon.

"The calibre has very much to do with penetration capabilities", says Hasslid. "On the 120 mm grenade, the weight of the penetrator is seven kilograms. Shot at 1700 m/s, it is practically unstoppable. The smaller calibres, for example 30 mm, are less effective. However the rate of fire can compensate for this: If fired from an automatic cannon capable of launching 200 grenades per minute, the cumulative penetration capability can also be very impressive."

For foot soldiers on the ground, things are different.

"For the soldiers, the task at hand will typically be to quickly stop an armored vehicle coming towards you in the battlefield", says Hasslid. The M72, one of Nammo's most exported weapons, is designed to do just that, and utilizes a quite different technology. A so-called High Explosive Anti-Tank warhead (HEAT), the 66 mm calibre weapon consists of a tube with a rocket projectile. Weighing in at a mere 3,5 kilograms, it is designed to be carried by individual soldiers, and gains its armor piercing ability from so called shaped charge.

projectile which, after the flight, hits the target with as low angle of impact as possible. It has a lot to do with materials, explains Hasslid.

"We use high density alloys of tungsten or refined copper. It is possible to use steel against steel, but the higher density metals double the effect", says Hasslid.

### HEAVY ALLOY

The heavy alloy is concentrated in an arrow, and the projectile is also equipped with steering fins for in-flight stabilization. This type of armour

"This works quite differently than the arrow ammunition", explains Hasslid. On impact, a charge is detonated off inside the projectile which in effect turns a copper cone inside-out. The chemical energy released by the charge in effect creates a copper rod which with sufficient energy to pierce through armor.

### SHAPED CHARGE

"Although the acronym HEAT would suggest that this type of ammunition actually melts its way through the armor, this is not the case", explains Hasslid. "It's the shaped explosion which supplies the kinetic energy, although there is produced considerable heat on impact which can have secondary incendiary effects after the penetration."

But what are the limits for armor piercing capability? In theory, almost none, but in practice, the ammunition is limited by each individual soldier's ability to carry the weapon, says Hasslid.

"The efficiency drops when the weapon gets too heavy. The M72 hits a fine balance between usability and armour piercing capability", he says. "Without divulging the exact numbers, a M72 has a window of effectiveness between 440-600 mm.

# CAPTAINING UNCERTAIN SKIES

**Morten Brandtzæg was just 11 years old when he made an important decision in his life – to become an aviator. It not only shaped who he is today, but also his perception of responsibility, safety and how to work hard to reach your goals.**

He went to France in 1974 together with his swim team. Morten was going to train and compete. But since he turned eleven right in the middle of the trip the team decided to give him a birthday gift. That gift would end up changing his life.

"I had no clue about their plans. But they told me to get dressed, we got in a car and started driving. After a while we ended up at a small airport, and there it was, a small plane. My teammates had pooled their funds and decided to give me a plane trip! It was just wonderful. And when we were airborne... I got that special feeling you really only get a few times in a life. Seeing the world from above - I felt that this was something I wanted to do. So I decided, right then and there, that I wanted to fly my own plane."

It would take a long time before that dream could be realized, but Morten did not give up. Two years later, he started as a paperboy and saved all the money he made. A tough job for a kid, but Morten pushed on.

"Of course it was tough. My family never had the money to pay for flight instructions, so I had to work towards this myself. Every morning, I got up early and started my route at 0430. It took two hours, six days a week, and I had to bicycle 25 kilometers. At least I got in shape! But after six years, I had saved enough money. I still remember the sum, 16.400 kroner", Morten says.

## **A BIKE TRIP TO THE LOCAL AIRPORT**

One sunny day in 1980, Morten got on his trusty bike and cycled to the local

airport, Kjevik in Kristiansand. He presented the money, asked the local pilot club to enroll him in their pilot classes and started on the next phase towards his dream.

"I told them I wanted to get my pilot's license. I ended up doing all the exams at the same time as all of my upper secondary school exams. That was pretty intense, but I passed. Getting all of the flight classes took more time though. But one day in February 1984, I finished that too."

*That's ten years – from when you decided as an 11-year old, until you finally got there?*

"True. But I had decided and did not want to give up."

## **WE MUST BE LIKE TOP ATHLETES**

Today, Morten is no longer a young and promising pilot. He's the CEO of Nammo, an aerospace and defense company specializing in advanced and niche products. Morten however believes his values are still the same: It's all about setting goals – and reaching them.

"Nammo is no ordinary company. We are different from many others in that we specialize much more. Our products are advanced, they are niche, and we need to re-invest a lot of the money we make back into research. And we absolutely need to keep the company very profitable. Otherwise we will lose that option to focus on inventing,

researching, and coming up with new concepts."

While Morten believes the economy of the company is important, he also feels it is just one of the elements needed for success.

"The economy is – at the end of the day – just the result of what happens on the technical side. And then there's the company culture, the people and the knowledge in the organization. We must nurture all of these and build towards our goal."

*What is the goal?*

"Well, we must never forget the users. A lot of them are soldiers who put their lives on the line: For their countries, or in a NATO or UN context. It would be an understatement to say they do an important job. In a historical context, Western democracies have had to fight for their values and their freedom. I strongly believe we still need that ability. And it is our responsibility to give them the very best tools. Our weapons and ammunition have to give them an edge on the battlefield – more range, more precision and more effect on target - because their lives depend on it. That is our goal. I also believe it's a duty, a moral obligation."

Morten believes Nammo employees have to think a bit like top athletes to get there.

"We must think and act like top athletes: Set goals and work towards them every day. We must improve, bit by bit. And if you think that sounds pretentious, or over the top – yes, maybe it does. I did

feel a bit ridiculous myself ten years ago, when we vowed to get to the moon with a Nammo rocket motor. But in 2019, we achieved that. (SpaceX's Beresheet Lunar Lander carried a Nammo-made rocket motor). We will go there a second time as part of ESA's HERACLES moon mission and I believe our Ramjet technology is an equally difficult task. Setting goals and getting there, that is immensely important. Without new goals, we will never develop new technology. I like doing the impossible, one step at a time."

### **BURNING ROCKET**

Successes are nice, but things don't always go according to plan. Morten Brandtzæg certainly has seen setbacks as well. Some have come in a Nammo context, some have been personal experiences. In 2015, he got a very disturbing call from the Nammo Test Center where a new prototype design for a hybrid rocket motor was being tested. After years of development and successful testing, he suddenly had a small disaster on hand.

"I remember that call very well. One of the test supervisors told me they had had a huge explosion on-site. As it turned out, the rocket motor prototype for the so-called Nucleus project had exploded, more or less destroying our test building. My first question was if there were any casualties. But there weren't. That was an enormous relief."



Nammo CEO Morten Brandtzæg, here at the "Presseverket" factory at Raufoss, Norway. Photo: Nammo

The rocket motor was a preliminary design with some potential challenges and a higher risk than usual. A new and different material was tested, it was part of the insulation inside the component chamber. But the rocket motor team got a so-called burn-through: The insulation failed and a part of the combustion chamber didn't hold the hot gases anymore. Long story short, the rocket motor exploded and the whole test building went up in flames.

"Sometimes we have to accept risk, but even though this mishap set us back – we lost time and money - no-one was harmed. We followed the safety protocols, shutdown was initiated immediately, and the engineers and testing personnel were physically separated from the rocket motor. So I wouldn't say it was just luck. We had taken a number of precautions, and they really helped save us from something worse. I also believe that we learned a lot from this incident. We rebuilt, improved the prototype and went on to make the Nucleus space rocket, one of the most successful designs in the history of our company."

### PLANE CRASH

And maybe one earlier experience helped Morten realize the importance of unharmed employees – as well as the

**One thing that makes me proud is that we have a lot of highly skilled people**

and he crashed it! He was unharmed, luckily. But still, I ended up having to rebuild it completely, and did all the work myself. It took me 3000 hours in my garage. But I still have the plane, and fly it from time to time. I don't like to give up", Morten says.

In one of his previous positions, Morten worked in Partnair, a Norwegian air taxi operator. He was one of the people responsible for handling a serious accident with several fatalities.

"I still think of the people killed there, from time to time. Aviation has some inherent risks. I believe that some of the mindset from that sector is relevant for the defense industry as well."

*What do you mean?*

"To me, it's all about two things. The first is risk management. I don't see it as an abstract thing that maybe the company should handle. It isn't! Risk is something very concrete that we all have to take responsibility for – on a personal level. We choose to follow safety procedures. We choose to wear protective clothing. We choose to stop and assess the situation if something seems off - and we never accept

determination to continue the work.

"Just after I got my pilot's license, I bought a home-made plane, an experimental. I lent it to a friend just a few months later,

unnecessary risks. The company's responsibility is to assess, set up procedures, lead by example, and make the right choices regarding risk. But doing the right thing is a personal choice. The second thing is that – as a company – we have to accept that safety has a cost. Sometimes we might have to stop production or take a step back if our employees see a risk. And we will never react negatively towards such employees even if they turn out to be wrong – because in the end, if we lose money or damage machines or structures, that's always much less important than peoples' lives."

### PRIDE

One of the most important goals for Morten (well, besides safety), is developing new technology and new concepts. He feels Nammo has succeeded in becoming a company that emphasizes advanced technology – and brings new concepts to market.

Morten feels that is demanding for the company, but sees no other realistic options.

"From a purely economic point of view, I don't think we have much choice. I don't think we would compete very well if we made bulk ammunition, for example. And by making specialized, high-end products instead - some of which no one else has - we play to our strengths."

*And what are those strengths?*

"One thing that makes me proud is that we have a lot of highly skilled people. That includes everyone from the lead engineers with PhD's to the operators. And I feel that there is a lot of initiative, at every level. Our production very



Sometimes, events involving shooting are arranged by Nammo. The company CEO sees that as an opportunity to test some of the company's products. Photo: Nammo



Morten takes a keen interest in what is going on at the company, and loves visiting the production facilities. Photo: Nammo



Morten loves to fly, and uses his small twin engine plane both privately, and sometimes for business trips.



rarely stops because the lead engineer isn't there - the teams working on-site most often show initiative, and just solve the problems then and there. Or they might come up with changes that improve the process, or even ideas for new products. We are an international company, but with Nordic roots, and I still believe that combination of skill and personal initiative is something we do well."

Over the years, several of Nammo's products have come from ideas conceived within the company. Morten mentions the M72, 30 mm ammunition and ramjet rocket motors as projects that have especially impressed him.

"We have made the world's first shoulder-fired system without a backblast: The M72 packs a big punch and can go through nearly half a meter of steel. And yet, it can be fired from

within a building. The 30 mm "Swimmer" ammunition can be fired through water and is unique. And I hope in time our ramjet missiles and artillery ammunition can really change the battlefield. If we are successful, we could change the entire NATO air defense with missiles that go five times as far as today."

A close-up, perspective view of several yellow and white rocket motors lined up on a dark metal production tray. The motors are conical with a white tip and a yellow body, separated by a red band. The central motor is in sharp focus, showing its base and a label with technical specifications. The background is dark and out of focus, emphasizing the industrial setting.

Nammo is an international aerospace and defense company headquartered in Norway. With more than 2 700 employees, 28 production sites and a presence in 12 countries, Nammo is today one of the world's leading providers of specialty ammunition and rocket motors for both military and civilian customers.

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