Technology Forecast 2014 Military Utility of Four Technologies
- A Report from Seminars at the SNDC Department of Military-Technology

Summary

Four technology forecast reports from the Fraunhofer Institute have been reviewed by staff at the Department of Military-Technology at the Swedish National Defence College. The task given by the Swedish Defence Material Administration, FMV, was to assess the military utility of the given technologies in a time frame to 2040, from a Swedish Armed Forces (SwAF) point of view.

We assess the **military utility of a certain technology** as its contribution to the operational capabilities of the SwAF, based on identified relevant scenarios. Since a new capability catalogue is under development at the SwAF Headquarters, we will only present general assessments of the capability impact from the technologies under study.

The technologies were grouped in three classes; technologies with potentially significant, uncertain or negligible military utility. The classification uncertain is given for technologies that are difficult to put in the two other classes, however it is not because the technology readiness level (TRL) is not reached by 2040.

The following technologies were assessed to have a potential for **significant** military utility;

- **Kinodynamic motion planning**
  This technology is a prerequisite for reaching full autonomy of highly agile unmanned systems and is probably a logical, evolutionary way to go forward. It will affect most SwAF capabilities through enhanced mobility. This technology should be studied by the SwAF, preferably within all operational environments.
- **Bio-inspired Adaptive Camouflage Surfaces**
  "Bio-inspired camouflage" should be viewed in a broad multispectral perspective involving design requirements for low contrast in the visual- and IR-spectrum as well as, for most applications, low reflectivity in the radar-band. There is an ongoing duel between sensor development and camouflage systems and our assessment is that the fewer and more valuable platforms we have, we will need better camouflage performance in order to maintain low probability of detection and short detection distances for an adversary, at least if faced with a technologically mature adversary. Our overall assessment is that bio-inspired adaptive camouflage systems have significant potential for military utility.
- **UCAV**
  If the idea that UCAV are superior in air combat is realizable, we may be facing a paradigm shift of the same magnitude as that which airborne radar or air-to-air missiles introduced. Thus, UCAV are deemed to have potential for significant military utility in future air operations even though it is, at present, hard to predict how they will be used to maximize their military utility.

The following technology was assessed to have **uncertain** military utility;

- **Bulk metallic glass (BMG)**
  If BMG innovations prove to form a new performance step in armour and weapons development, it will from a Swedish perspective be crucial to take part in that development or else take the risk of being inferior on the battlefield. Given the many uncertainties concerning production and applications, we assess BMGs to have uncertain potential for military utility in 2040. However, the SwAF should monitor the development and applications in this area.

None of the studied technologies were found to have **negligible** military utility. .

The method used in this technology forecast report was to assign each Fraunhofer report to one reviewer in the working group. First, a summary of each forecast report was made. The Fraunhofer assessment of technical readiness level (TRL) in 2030-40 was held to be correct. The technology was then put into one or more scenarios that were assessed to be suitable in order to assess the military utility as well as indicate possibilities and drawbacks of the technologies. Based on a SWOT-analysis, the contribution to SwAF capabilities and the cost in terms of acquisition, C^2 footprint, logistic footprint, doctrine/TTP, training, facilities and R&D were assessed. Finally, conclusions regarding the potential military utility of the technology were drawn.

The chosen definition of military utility clearly affects the result of the study. The definition (the military utility of a certain technology is its contribution to the operational capabilities of the SwAF, within identified relevant scenarios) is the same that was used in the Technology Forecast 2013. It is believed to be good enough for this report, but could be further elaborated in the future. An article that in depth presents our concept of military utility has been elaborated at the department.[1]

Our evaluation of the method used shows that there is a risk that the assessment is biased by the participating experts' presumptions and experiences from their own field of research. The scenarios that were chosen do not cover all aspects of the technology and their possible contribution to operational capabilities. It should be stressed that we have assessed the four technologies' potential military utility within the specific presented scenarios, not the technology itself. When additional results have been found in the analysis this is mentioned.

The greatest value of the method used is its simplicity, cost effectiveness and the tradeoff that it promotes learning within the working group. The composition of the working group and the methodology used is believed to provide for a broad and balanced coverage of the technologies under study. This report provides executive summaries of the Fraunhofer and Recorded Future reports and the intention is to help the SwAF Headquarter to evaluate the military utility of emerging technologies within identified relevant scenarios.

Overall, the quality of the Fraunhofer reports is considered to be balanced and of a high level of critical analysis regarding technology development. These reports are in line with our task to evaluate the military utility of the emerging technologies.

We appreciate that the Department of Military Technology at SNDC this time has been involved in the early phase of the Technology Forecast process.

[1] K. Andersson et al, *Military utility, a proposed concept to support decision-making*, 2014, submitted to Philosophy and Technology.

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Introduction

Scope
This report is the result of a review of four technology forecast reports from Fraunhofer Institute.
The review was carried out at the Swedish National Defence College by staff at the Department of Military-Technology, commissioned by the Swedish Defence Materiel Administration, FMV. The task was to assess the military utility of the different technologies in a time frame to 2040.

The review and evaluation of the technology forecast reports form one chapter each in this report.

References
The following reports, composed at the Fraunhofer Institute for FMV, were reviewed:
[1] Kinodynamic Motion Planning, Fraunhofer INT, December 2013
[2] Bulk Metallic Glass, Fraunhofer INT, December 2013
[3] Bio-inspired Adaptive Camouflage, Fraunhofer INT, December 2013
[4] UCAV, Fraunhofer INT, March 2014

Definitions
We define **military utility of a certain technology,** as its contribution to the operational capabilities of the SwAF, within identified relevant scenarios.

Method
The method consists of four steps and was chosen in order to be efficient and take advantage of the professional expertise of the reviewer.

Step 1: The reports were distributed among the participants of the working group, on the basis of their special interest and expertise. Each reviewer was responsible for reviewing one report. The reviewer wrote a summary of the report and defined one (or more) tentative military technical system and put it in a possible scenario for the Swedish Armed Forces in the timeframe to 2040. The purpose of each scenario is to illustrate the usefulness of the technology and hence to be as convincing as possible while being in accordance with the reported technology forecast.

Step 2: Each review was discussed at a seminar. The reviewer briefly introduced the technology and presented the technical system concept and the scenario. The reviewer's role was to be an advocate of the military utility of the technology. The other participants' role was to support or criticize the concept. At the seminar a SWOT-analysis, an assessment of the technology contribution to SwAF capabilities and an assessment of the cost was made.

Step 3: The result of the seminar was documented and conclusions on the potential for military utility of the technology were drawn. The footprint/cost of each technology was assessed and summarized in a table.

4. Finally, the results were summarized in a Capability Matrix at the end of the report.

The composition of the working group

The working group consisted of staff members from the Department of Military Technology at SNDC:

Stefan Silfverskiöld, Cdr (N), PhD, project manager
Peter Bull, Associate Professor of Military-Technology
Gunnar Hult, Chaired Professor of Military-Technology
Åke Sivertun, Professor of Military-Technology
Michael Hagenbo, LtCol (AF)
Kent Andersson, Lt Col (AF), Licentiate of Technology
Björn Persson, MSc
Johan Sigholm, Capt (AF), MSc
Peter Sturesson, Capt (AF), MSc

Kinodynamic Motion Planning - Path Planning for Highly Agile Unmanned Systems

Ref: [1]

Introduction

Kinodynamic motion planning refers to systems capable of taking both kinematic and dynamic boundary conditions into account. Kinematic boundary conditions are physical obstacles in the systems path, and dynamic constraints are coupled to permissible accelerations and velocities in the system itself. The area of research stems from attempts to increase the efficiency of industrial robots [a]. The motion along a certain path of a tool held by an industrial robot can have several solutions and finding the optimum one is the key to improving the efficiency of the robot.

Similarly, unmanned systems can benefit from kinodynamic motion planning if, for instance, the aim is to get the system from one point to another in the shortest amount of time. One example is a UAV able to maneuver between trees in a wood and land in a very limited space such as on a wire or a twig. Other options could be to optimize the system for endurance or range, it could even be possible to optimize for cost or mean time between failures [b].

Identified possibilities and constraints

The systems presented in the report [c] are solely prototypes or demonstrators. The aircrafts depend on external sensors in order to maneuver as they do, and the vehicles are still not as fast or as accurate as the best of drivers. E.g. the autonomous Volkswagen Passat used by Stanford University is capable of parallel parking within about 60 cm from the desired location [d] whereas the world record for parallel parking is to place the car in a space that is 13.1 cm longer than the car [e].

Advantages

- Capability to take a system very close to its breaking point without actually breaking it
- Possibility to optimize running for agility, speed, range, endurance, and/or cost

Disadvantages

- Requires very advanced local situational awareness systems in order to work properly
- Requires very high computing power in order to simultaneously interpret results from LSA system, keep track of system health, and continuously plan optimal paths

Assumptions

The concept scenarios are based on the following assumptions.

- Computing power is not a bottleneck
- Sensors able to give the vehicle an adequate local situational awareness are available

Suggested military use

Kinodynamic motion planning can be used not only to increase the agility of unmanned systems, but also as highly competent driver/operator support systems.

The following applications are mentioned in the report:

1. Unmanned ground vehicles (UGV)
2. Walking robots
3. Micro unmanned aerial vehicles (MAV)
4. Driver assistance systems

Concept scenarios in 2040

Two scenarios are presented and subdued to a SWOT-analysis.

Scenario 1 Increasing probability of survival for a UAV subjected to anti-aircraft missile threat

The level of self-protection on UAVs is relatively limited. Even though there is no pilot in a UAV the larger and more qualified ones are still relatively expensive and not readily sacrificed. Therefore the use of qualified UAVs is to a large extent limited to an environment where complete air superiority is maintained.

Modern anti-aircraft missiles use an imaging infrared seeker. The seeker builds up an image of the target, which makes it difficult to fool the seeker into following a decoy rather than the aircraft. Anti-aircraft missiles use a Kalman filter to predict the movement of the aircraft it is aiming for. The filter uses rules built on how an aircraft moves in the air and tries to predict where the aircraft will be a minute moment of time into the future in order to catch up with, and hit the aircraft.

Because the Kalman filter is based on how an aircraft is supposed to move, one possible way to avoid an anti-air missile is to make the aircraft behave in an erratic or unpredictable, un-aircraft-like way.

The technology is exemplified by an experimental UAV having a structure capable of withstanding high loads in all six degrees of freedom and control surfaces capable of generating high loads in all six degrees of freedom. The UAV is equipped with a local situational awareness (LSA) system capable of keeping track of objects in the vicinity of the aircraft, and a system for monitoring the loads and health of the UAV. It is also equipped with a control system capable of very advanced kinodynamic motion planning

When an anti-aircraft missile approaches it is detected, and identified, by the LSA system. The control system has a threat library of missiles containing information of which maneuvers and combinations thereof that a certain missile might have problems with. Depending on possible weaknesses of the missile, and when the missile reaches a certain distance from the aircraft, the UAV enters a series of moves. Remaining external payload is dropped at the most beneficial time in order to enhance the maneuverability, e.g. if a certain move benefits from the aircraft being loaded asymmetrically, only payload on one side is dropped. The moves are violent enough to kill a pilot had one been onboard the aircraft, and almost violent enough to terminally damage the aircraft structure. The purpose of the orchestrated moves is to “get inside the OODA loop” of the anti-aircraft missile, thus causing it to miss the aircraft.

The aircraft is not expected to succeed every time, but depending on circumstances getting back a few aircraft rather than none might be worth the risk.

SWOT-analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within scenario 1 were identified at the seminar:

<u>Strengths:</u>

- Increased probability of survival
- Reduced sensitivity/vulnerability to anti-aircraft missiles

<u>Weaknesses:</u>

- System might not work

Opportunities:

- Possibility to utilize UAV in very high risk situations
- Might be utilized as pilot support system in manned aircraft
- Might increase safety, or reduce risk of collateral damage

Threats:

- UAV might still be shot down
- Anti-aircraft missiles will develop

Scenario 2 High-speed logistics support vehicle

In military operations there is a high demand on logistics, and as such logistics convoys are high value targets. A set of trucks with off-road capabilities is equipped with a control system consisting of an advanced LSA system and a system for monitoring vehicle health. The latter can keep track of engine, transmission and suspension health as well as the load and stress levels these components are subjected to. Based on field tests as well as earlier missions the control system can optimize vehicle speed for targets such as maximum range, shortest time to destination, or maximum probability for success.

In an operation, when the vehicles are travelling, the control system will prioritize between vehicle speed, vehicle range and allowable load levels on the vehicle. If the vehicle is subjected to high loads the probability that something to break will increase. With a database of load versus mean time to failure the control system can calculate the probabilities for parts to fail at a given load, and thus keep the maximum loads at acceptable levels. In this way the vehicles can minimize the amount of time spent in high-risk areas by not just increasing speed but also by reducing the probability of components to fail.

SWOT-analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within scenario 2 were identified at the seminar:

Strengths:

- Reduced logistics transport times in the field
- Maximized endurance in the field

Weaknesses:

- System might not work and render vehicle stranded

Opportunities:

- Possibility to deliver supplies in very high risk areas
- Possibility for randomized behavior in unmanned vehicle convoys

Threats:

- Vehicle might be hijacked
- Safety issues

Assessed capability impact

Kinodynamic motion planning can be utilized by almost any type of system. It is therefore assumed to impact most of the capabilities as defined by the SwAF catalogue. Therefore no specific capabilities are presented.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of systems utilizing kinodynamic motion planning.

Item	**Comment**
Acquisition cost/system	One more advanced system that adds to the cost of a complete system
Chain of command footprint	Little, depending on application
Logistic footprint	Depends on whether the control systems are incorporated in existing systems or new systems
Doctrine/TTP	Need to make changes to doctrines and TTP's in order to fully exploit the potential of these control systems
Organization	Possibly lower risk of losing personnel. New organization due to changed TTP.
Training	Handling and maintaining these control systems requires specialist knowledge
Facilities	Little
R&D	High, these systems have not yet reached maturity

Discussion and conclusions

Kinodynamic motion planning is just one piece in a larger puzzle. When conducting maneuvers on the edge[2] of what a system is capable of, it would obviously be preferable if the system reached its destination undamaged, or at least in an acceptable working condition. In order to achieve this, the unmanned system needs a system for ensuring an adequate degree of local situational awareness (LSA). In addition it needs at least a set of rules for maintaining its own health, but a system for monitoring component and system health would possibly be preferable. A set of rules would require relatively large safety margins in order to be confident that the system would not damage itself. Such safety margins could be made smaller if the system was able to monitor both the strains it was subjected to and its resulting system health. In that way it would be possible to get closer to the system almost breaking itself in pieces, but still managing to fulfill its task. This technology is a prerequisite for reaching full autonomy and is probably a logical, evolutionary way to go forward. It will affect most SwAF capabilities through enhanced mobility and hence it is assessed to have potential for significant military utility. This technology should be studied by the SwAF, preferably within all operational environments.

[2] As close as possible to, rather than in the general vicinity of…

References

[a] J.E. Bobrow, S. Dubrowsky, and J.S. Gibson, *Time-Optimal Control of Robotic Manipulators Along Specified Paths*, The international journal of robotics research, vol 4:3, 1985

[b] K. Bergman, *Mine of the future: Australian mines lead the world into autonomous mining,* AUVSI Mission Critical, vol 3:1, 2013, Washington DC, USA, 2013

[c] G. Huppertz, *Kinodynamic Motion Planning – Path planning for Highly Agile Unmanned systems*, Fraunhofer Institute for Technological Trend Analysis, Euskirchen, Germany, 2013

[d] J. Ziko Kolter, C. Plagemann, D.T. Jackson, A.Y. Ng, and S. Thrun, *A Probabilistic Approach to Mixed Open-loop and Closed-loop Control, with Application to Extreme Autonomous Driving*, IEEE International Conference on Robotics and Automation 2010, pp 839 – 845, USA 2010

[e] K. Lynch, *Video: brothers both beat tightest parallel parking record,* http://www.guinnessworldrecords.com/news/2013/3/video-brothers-both-beat-tightest-parallel-parking-record-47748/, March 2013, accessed 2014.03.31

Bulk Metallic Glass

Ref: [2]

Introduction

As continuous materials in the solid state, metals are arranged in specific orders, i.e. in crystals structures. Bulk metallic glasses (BMG) are metals whose atoms are disordered without this structure; this difference in arrangement on the atomic scale forms the basis for a different material group with some common and some fundamentally different properties.

As materials they possess the general metal-related properties of thermal and electrical conductivity but also strength-related properties such as yield strength, elasticity modulus and wear resistance of ceramics as well as the plastic and elastic properties of polymers. Crystalline metals deform when grains move along boundaries or when dislocations in the atomic structure moves through the grains. When internal movements constrain each other, additional deformation will be permanent, as it would otherwise be reversible. Ceramics would behave in a similar way but due to their high strength they deform very little in an elastic way and will fail due to stresses around internal voids before any plastic deformation takes place. Polymers deform when the hydrocarbon chains reorient and align themselves. BMGs have no grain boundaries and will deform similarly to polymers, although they will also face failure when the stress is too high around an internal void, similarly to ceramics. This implies that BMGs are metals with some properties that are usually related to polymers and ceramics.

As a consequence of these properties, BMGs are sometimes labelled as “amorphous metals” or “liquid metals”, the latter should not be confused with proper liquid metal technologies.

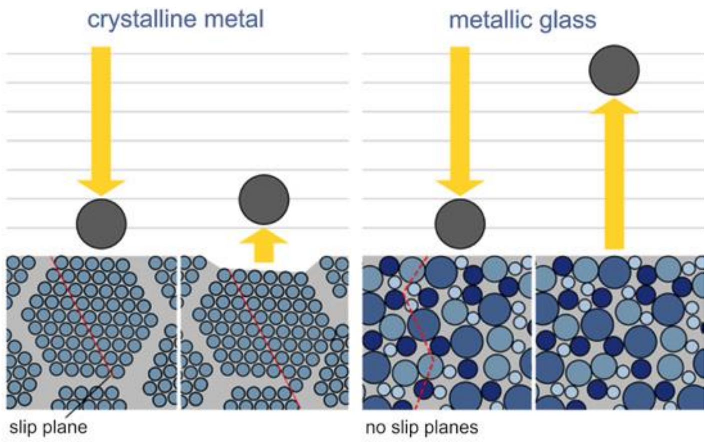

Figure 1. Illustrated difference in stress and deformation distribution between crystalline metals (left) and BMGs (right) when exposed to an external load. The illustration also visualizes the difference in atomic structure.

Development and processing

BMGs have been known since at least the 1960´s and have attracted an increasing interest during recent years. They are sometimes regarded as materials of the future alongside with graphene and other nanostructured materials.

There are three main reasons for the increased interest:

- As a material group, BMG combines material properties in an unprecedented way.
- They are now developed to be stable in their disordered form without being crystallized over time

- The process of both raw materials and resulting components and products are available and affordable for many actors.

If heated, BMGs can be shaped by molds, both by pressing and by injection. This allows BMGs to be pressed through a nozzle, quickly forming a small specimen due to the rapid cooling as it is let through the nozzle, the basis for 3-D printing.

In practice this means that a private person as well as an R&D institution in time can buy a 3-D printer and manufacture their own systems. A vehicle manufacturer can develop and produce parts without having to consult subcontractors although a number of new companies or even a new supplier market can easily be expected to grow.

Contemporary example

Material development of BMGs is still modest, as of 2014 only 49 international patents containing "bulk metallic glass" in the title are registered and the research is dominated by California Institute of Technology and Yale University.

For the IPhone 3G, Apple Corps Ltd. used a licensed and novel 3-D printing technology to fabricate the SIM-card ejector. The license was prolonged to at least February 2014 but in May 2013 a patent called "Layer-by-layer Construction with Bulk Metallic Glasses" was filed by the company and at least two more process-related patents have been filed since 2011. There are reports in the press as of November 2013 that future parts in electronic devices will contain BMG-based solutions.

Identified constraints

The reviewer has identified the following technological advantages and disadvantages:

Advantages (as compared to conventional bulk materials)

- High material strength properties combined with low density
- Can be processed into components and products with simple and cheap fabrication methods such as molding and 3-D printing
- High wear resistance and low corrosion in harsh environments
- Can be superconductive
- Can be available for prototype development by non-metallurgical industry and research facilities

Disadvantages

- Simple forms of BMG can only be processed into very thin substrates
- Form stable BMGs are highly alloyed and this demands rare and expensive metals that are energy consuming to extract and exist in a limited number of countries
- Errors in raw materials can cause them to behave as ceramics in a more brittle way causing failures in load-bearing structures
- Electrical properties such as superconductivity are so far only expected at low temperatures and the magnetic properties can cause heating when exposed to a radiative environment.
- Very little raw material production of important elements is produced in Sweden.

Assumptions

The concept scenarios are based on the following assumptions:

- Sweden has a global dependency regarding raw material and process technology for sustaining a domestic military industrial capability.
- Other actors can use some dependencies in order to coerce Sweden to subject their will.
- Sweden has a strategic aim for mitigating threats to any strategic vulnerability concerning industry and research and technology.
- Unpredicted situations demanding rapid prototyping of components and systems are regarded as vital for continuous modification of existing systems.

Suggested military use

The following applications are mentioned in the report: As a group of materials, BMGs are not to be viewed as stand-alone contributors to military capabilities and do not comprise entire systems. Specific military use is instead described in the field of design and manufacturing of components and subsystems in military systems. The mechanical, electrical and magnetic properties are suitable to be used in military applications. Most likely, BMGs will add to the performance of existing system technologies and at its best, new generations of known technologies can be based on BMG thus containing a number of novel technological solutions. The main areas of application are composite materials, mechanical structures, penetrating warheads and armour, figure 4.

Taxonomy	Designation
A01.01	Metals & Metal Matrix Composite Technology
B01.05	Structural Materials Processing – Surface Protection Technologies
B01.02	Penetrators
B01.07	Armour Systems

Figure 2. Summary of the most likely military contexts in which bulk metallic glasses may be used.

If yet unclear, the FH report states that all taxonomies as well as critical parameters will reach at least TRL 7 by 2030, figures 3 and 4. This implicates that BMGs will likely be used in military systems in 2014, at the latest.

Taxonomy	Designation Year	2012	2015	2020	2025	2030
C02.04	Coatings	8	8	9	9	9
C02.04	Small components	6	7	8	8-9	9
A10.04	Structural materials	4	5	6	7	7-8
C02.03	BMG for bio-medical applications (e.g. implants)	3	4	5-6	7	8
	BMG-matrix-composites	3	4	5-6	6	7

Figure 3. Short summary of technology readiness levels (TRL, 1-9) of some identified applications of BMG.

Critical Parameter	Description YEAR	2012	2015	2020	2025	2030
Fabrication	*Lowering fabrication costs*	6	7	7-8	8	9
Maximum thickness	*Achieving BMGs of cross sections > 3 mm*	5	5-6	6	7	7
Ductility	*BMGs ductile enough for load-bearing applications*	5-6	5-6	7-9	7-9	7-9

Figure 4. Short summary of technology readiness levels (TRL, 1-9) of some critical parameters for BMG´s to evolve as a widely and successfully used group of materials.

Concept scenario in 2040

As of 2014 future wars are predicted to switch, with an increasing pace, between different phases and different characteristics, as described by a conflict spectrum. In 2030 there is a need to develop and assess military systems in response to this threat while being constrained by unpredicted budget fluctuation between fiscal years. Development of weapons and protection systems has increased performance in terms of impact velocity, warhead effect, and mass and volume efficiency. Even smaller hand-held arms are effective in terms of penetration.

Research and development projects are forced to perform short-time iterations as achievements within material science, geopolitical changes and the supply-and-demand of natural resources lead to changes in the prerequisites of capability development.

The duel between measures and counter-measures for armour and penetrators is, together with the efforts to reduce energy-consumption boundary conditions, of increasing importance.

Political changes in South Africa causes a degradation of the production of noble metals and China chooses to restrain the export of rare earth metals in order to coerce USA and the European Union to withdraw financial support to Uyghur freedom movements. At the same time Russia and Belarus have instituted a trading union with central Asian countries and China as a means to degrade European political power and economic stability within the European Monetary Union. This is underpinned by a security-doctrine based on aggressive behaviour with conventional forces as well as a high activity of subversive actions in various countries, using it for tactics and systems evaluation.

SWOT-analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology were identified at the seminar:

<u>Strengths:</u>

- Combining many material properties from other conventional material groups such as metal, polymers and ceramics.
- Can be tailored with magnetic properties if the alloy components are suitable.
- Can be formed with cheap and simple methods.
- Exhibits suitability for rapid prototyping.
- Can be developed for both armour and penetrators.

Weaknesses:

- Limited size in at least one dimension.
- Still brittle in normal temperature ranges.
- Not all consequences of tailored properties are discovered.
- Alloys are dependent on rare elements limited to a few countries in the world.
- Hard to combine with other materials without risking crystalline growth, i.e. to integrate into other systems.

Opportunities:

- Components can achieve high strength at low mass.
- Production can be available within non-traditional industries.
- Cheap prototyping can be accessible and available for many actors.
- Penetrating warheads can be developed using the high yield strength properties.
- Using its elastic-plastic properties can develop Armour.
- Can be used for absorbing magnetic fields.

Threats:

- Unknown time-dependent mechanisms can deteriorate BMGs properties over time.
- Dimensional changes due to heating can cause stress in load-bearing structures.
- Irregular actors with aims to produce weapons and munitions in simple facilities can benefit from technological achievements.
- Antagonists might subject Sweden to import sanctions in business or politics, thus affecting domestic production.

Assessed capability impact

BMGs will help maintain a broad range of capabilities in the SwAF catalogue indirectly. Since it is difficult to specify which capabilities are affected, no specific capabilities are presented apart from the general bullets bellow:

- Capability development/Research and Development projects.
- Rapid prototyping.
- Increased performance in future generations of vehicles, protection, weapons and sensor systems.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the technology:

Item	**Assessment**
Acquisition cost/ System	Lower if raw material prices are low and process technologies are widespread. High if some material components are used as strategic measures by some countries.
C2 footprint	NIL
Logistic footprint	Less tonnage in supply chain due to in-situ 3D-printing
Doctrine/TTP	Can contribute to changes in R&D strategies
Training	NIL
Facilities	Easy to implement into existing R&D and industry facilities
R&D	Great improvement of rapid prototyping

Conclusions on military utility

Bulk metallic glasses are a group of materials comprising a combination of electrical and mechanical properties that are of interest for developing and manufacturing of military systems. Specifically the development of process technologies is expected to have the most likely implications on military capabilities and activities by making bulk metallic glasses more available to state- and non-state actors for prototyping and low-scale manufacturing.

In conventional systems, the degree of change in capabilities is so far difficult to predict as the level of utilization of BMGs in contemporary and future innovations and systems is unknown. However, a less benevolent implication is the potential use for reactionary irregular actors to manufacture more advanced IEDs and even smaller weapons. This would rather call for the development of capabilities that can neutralize features that are based on BMGs, such as warheads on BMG-based protection and countermeasures on BMG-based weapon systems.

It cannot be predicted what the cause-and-effect between penetrators and armour will be, it is only likely to depend on research success or failure within the next ten years. Furthermore, whatever BMG innovations will be feasible, industry will probably use them if pulled by customer requirements in a direction that will leave them with no other choice.

If BMG innovations prove to form a new performance step in armour and weapons development, it will from a Swedish perspective be crucial to take part in that development or else take the risk of being inferior on the battlefield. From this analysis it is suggested that the development and applications of BMGs are studied over time.

Bio-inspired Adaptive Camouflage Surfaces

Ref: [3]

Introduction

This reviewed report from Fraunhofer assumes that adaptive or active camouflage for soldiers or military objects is a highly valuable capacity. The idea is to mimic the extraordinary features of animals, such as chameleons, zebra fish or octopus, being able to blend in with their surroundings by changing the color and the surface structure of their skin as they move along. A simple system model of such an adaptive camouflage system consists of three major building blocks: a detection system, a control and information processing system and the camouflage organ/system. See the illustration.

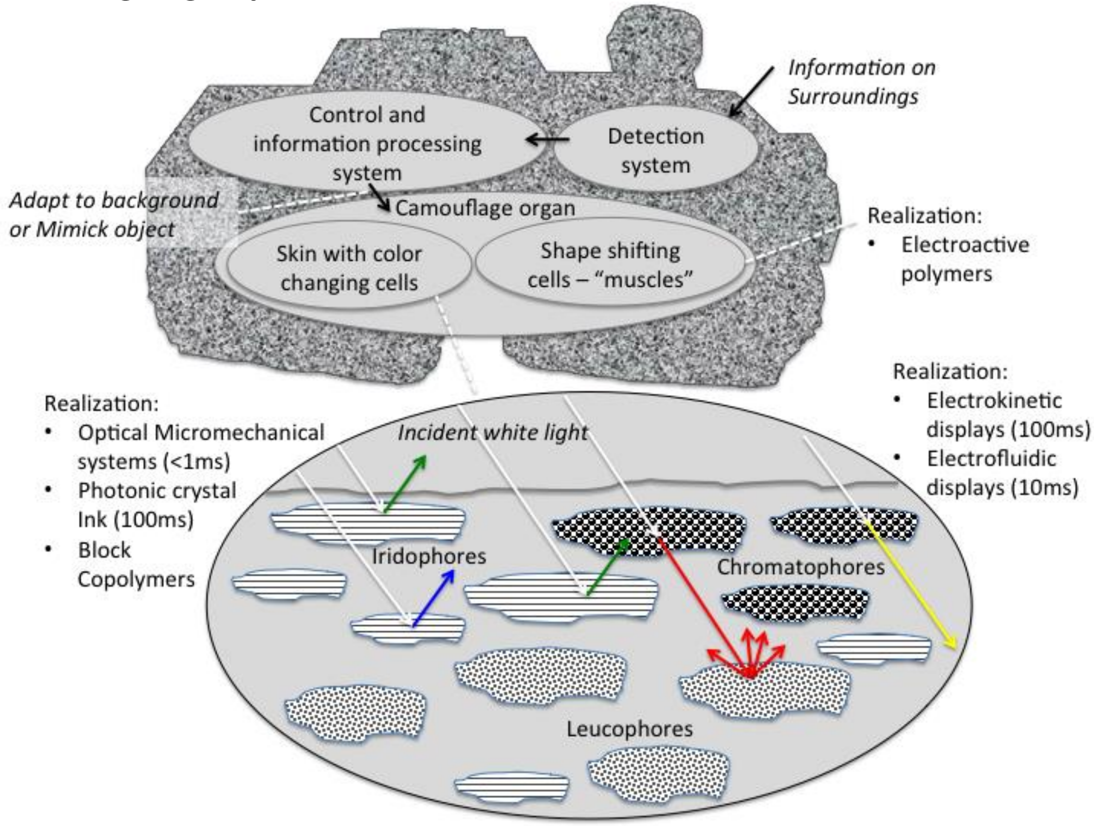

Figure 5 The upper half illustrates a system model of an adaptive camouflage system. The lower half illustrates the light interacting features of different types of color changing cells. Technologies for realization of Iridophores (left) and Chromatophores (right) are listed.

The Fraunhofer report states that the detection and control parts of the biological camouflage systems are very complex and that research up till now has concentrated on understanding the color changing properties. The strategies seem to be either to mimic an object in the surroundings or in the background. There are three different types of cell near the skin surface that makes color change possible. **Chromatophores** carry pigment granules that can be elongated or squeezed by muscles. The pigments are red, yellow or black/brown. In other species the chromatophores depend on a pigment colored liquid, slowly translocated from sub dermal cells. **Iridophores** create the colors green and blue through nanostructural features. The cells have a lamellar structure where variable distances between the lamellas create color through interferences. **Leucophores** reflect and scatter light without changing the spectral composition thereby contributing to the general color adaption.

Military sensors are becoming hyper spectral and hence it is not enough to be camouflaged in the visible spectral region. Fraunhofer has however not found any known examples of biological camouflage in the infrared region.

An artificial bio-inspired adaptive camouflage system should

- have a combination of optical systems incorporated in a flexible medium – a "skin", e.g. a flexible display or flexible polymer.
- not need additional illumination
- have a multitude of colors, rich in contrast
- have the capacity to form a texture at the surface (limiting gloss, my remark)

Adaptive camouflage systems are at present not regarded a "hot topic", but some of the sub-technologies are driven by civilian industry, such as display technologies, polymer engineering and miniaturization of electronic devices, etc.

Chromatophore-like systems are available in the form of electro kinetic display technology, e-ink, where charged pigments can be dispersed or concentrated allowing color changes under100 ms. The technology allows polymer as substrate material and hence enables flexible design. Another technology uses a droplet of pigmented ink spread or compacted in a pixel via its surface tension. It is called electro fluidic display. Shifts within 10 ms are expected.

Iridophore-like systems can be realized by optical micromechanical systems using electrically switching membranes on a backing material. Depending on the distance between the membrane and the supporting material different wavelengths of light are reflected. Combining pixels with different properties can create multicolored systems. Shifts within 1 ms are expected. One can also use photonic crystal ink containing ordered layers of microspheres surrounded by polymer. If the ink is made to expand or contract electrically, the distance between layers of microspheres will change resulting in a color shift in the reflected light.

The assessed TRL for 2030 is 7-8, for the technologies mentioned above, i.e. some systems will be operational.

There are also attempts to use so-called block copolymers to mimic the laminated structure of Iridophores, but the TRL is assessed to be lower.

Other technological approaches identified:

Some attempts at combining visual camouflage with infrared are reported. Transparent polymers with high elasticity are used pervaded by micro channels. Color change is managed by flooding the channels with colored ink. By heating and cooling the ink, shifts in the infrared spectrum are obtained. The TRL is assessed to be 4-6 in 2030.

Other attempts to create camouflage systems using OLED technology and other diode approaches are also reported, though not considered as being bio inspired. In yet other approaches one can use projection of a picture on to the object etc.

Identified possibilities and constraints

The following technological advantages and disadvantages have been identified by the reviewer:

Advantages (as compared to static traditional camouflage structures)

- Overall functional flexibility,
- Better surface (skin) flexibility,

- Angle independent reflection,
- Coloring as well as texturing of the surface,
- No extra illumination necessary,
- Higher energy efficiency

Disadvantages (as compared to static traditional camouflage structures)

- The complex technology - "…the combination of different optical strategies into one lightweight, flexible, energy efficient and durable system" is a challenge
- Uncertainties in the Technical Readiness Levels
- Higher manufacturing cost (assumed by reviewer)

Assumptions

The concept scenarios are based on the following assumptions:

- The technology is optimized for camouflage capabilities exploiting reflective properties of materials, hence creating adaptive camouflage optimized for the visible spectral region.
- Precise reproduction of pictures on any object, from any angle is unlikely to be possible at any time. Some viewing angles will have to be prioritized
- Only relatively high value assets would have this capacity in 2035
- Movable objects not possible to camouflage in a static setting benefit the most from the technology, but also static objects with changing surroundings (weather, day or night, seasons)
- The technology is not for platforms where the main threat is a radar sensor, i.e. applications are for ground or littoral environment platforms or objects
- A bio-inspired technical system changes its appearance and adapts to the background automatically, without the real-time need of a human operator.

Suggested military use

The following applications for bio-inspired adaptive camouflage surfaces are mentioned in the report:

- A general assumption is that adaptive camouflage/stealth is a valuable military capacity. This new technology would facilitate camouflage for movable objects or while moving between places with different backgrounds
- Could primarily be used to disguise objects, especially if arranged in front of a specific background.
- Camouflaging unmanned vehicles was suggested, since there is no personnel available to do it manually
- Camouflage of soldiers, e.g. special forces
- Bio-inspired shape shifting mini robots
- Elimination of blind spots for a driver/pilot
- The hiding of cameras

Concept scenario in 2040

The following scenarios were considered for the seminar

- Camouflage costume for SF soldier
- A Chameleon Archer Artillery System (chosen)
- A C2 vehicle

Description Chameleon Archer artillery system

In 2035 Sweden has acquired a new Mobile Adaptive Camouflage System for the Archer Artillery System replacing the former static version. The system has a sensing system initiating a change in skin color pattern, which makes it possible for the Archer to adapt to changing backgrounds within half a minute. Adaption can be done on the move, and to a moving background.

Since one of the most dangerous threats to the artillery unit is other artillery units and their capability to measure coordinates of firing artillery in near real time, it is necessary to use shoot and scoot tactics. In a national defense scenario the Archer typically rolls in to a clearing in the Swedish coniferous forest and stops to prepare for firing. The gun is ready to fire within 30 seconds and the system is on the move again in another 30 seconds after the last round. The new Mobile Adaptive Camouflage System considerably increases the possibility to find camouflage in all terrains, even Swedish farmland with occasional copses. The new camouflage system is applied to both the artillery gun platforms and to the ammunition resupply vehicles.

The tactical threats are enemy TAC-parties, helicopters or UAVs using optical/IR/multispectral sensors and the strategic sensor threat is from optical /IR or SAR satellites. In order to meet the multispectral sensor threat, some accompanying measures have been made to the Archer system, such as the cooling of the barrel protection chamber, the engine cover, exhaust etc. The Mobile Adaptive Camouflage System is low emissive, yielding a generally low contrast in the IR, but the adaption span is smaller than in the visible.

In summary the systems decrease the probability of detection and hence increase survivability and durability of the Archer high value asset system.

Some adjustments in the capability system have been necessary. The Adaptive Camouflage System demands special maintenance to keep it clean, and hence maintaining its camouflaging capabilities. Furthermore, it is sensitive to wear and tear.

SWOT-analysis

The following strengths, weaknesses, opportunities and threats with the proposed bio-inspired adaptive Camouflage Surfaces were identified at the seminar:

<u>Strengths:</u>

- The probability of detection while standing still and hiding is decreased
    a. offering hiding places in a larger fraction of Swedish terrain
    b. possibly increasing the effect of the element of surprise
    c. camouflage is effective immediately after reaching a new position
- The probability of detection while on the move might be reduced through continuous adaption to the background
- Soldiers do not have to work outside the protective armor to camouflage the platform

<u>Weaknesses:</u>

- Dirt from transport or atmosphere degrades the camouflage capability
- Ground platforms are roughly handled and a “sensitive skin” would quickly be degraded, i.e. the system is sensitive to wear and tear
- Some electrical energy is needed – though probably a smaller load with bio-inspired technology than other

<u>Opportunities:</u>

- This technology is one way to manage the duel between sensors and camouflage. It will contribute to shorter detection ranges i.e. longer time before detection. Another approach to describe this is that the system could enable us to maintain engagement distances in spite of more effective, multispectral sensors on the adversary side.
- An adaptive camouflage can be used for new capabilities, e.g. IFF, deception or “Psyops” applications
- IFF-codes might be displayed in certain aspect angles to friendly forces while maintaining the camouflage towards adversary sensor angles

<u>Threats:</u>

- Vehicle tracks are hard to cover in terrain with soft surfaces, this will not be addressed with camouflage
- The muzzle pressure can damage the camouflage capability
- A malfunction of the camouflage system might put the crew in dangerous or vulnerable situations
- The adversary might develop countermeasures to the adaptive camouflage system, e.g. to somehow trigger the system in order to enhance the contrast to the background instead of adapting to it. This might be done by stimulating the ACS detection system or jamming/hacking the control and information processing system.
- New sensors in other spectra might make the system obsolete

Assessed capability impact

Bio-inspired adaptive Camouflage surfaces will contribute to many capabilities in the SwAF catalogue. Since the catalogue is under revision, no specific capabilities are presented apart from the general bullets bellow:

Increased survivability for ground or amphibious platforms, i.e. directly supporting:

- The capability to protect objects.

And indirectly supporting:

- The capability to affect targets

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by bio-inspired Adaptive Camouflage Surfaces in use.

Item	**Assessment**
Acquisition cost/ System	New adaptive Mobile Camouflage Systems will probably be expensive, but not compared to maintaining a permanent camouflage skin on vehicle systems. An Adaptive Mobile Camouflage System will however not be the only measure taken to reduce signature.
C2 footprint	There will have to be some sensing and information processing systems integrated with the existing vehicle automatically adapting to the background. No additional C2 capacity is needed.
Logistic footprint	The need for maintenance is probably greater than for mobile camouflage systems today.
Doctrine/TTP	Some tactical procedures will probably have to be developed in order to maximize the potential of the technology – creating new functionality. If the ambition is to just maintain the balance with sensor development, no new tactical procedures or doctrines will be necessary.
Training	Yes, some additional training on the new TTPs and the maintenance of the new systems.
Facilities	Small impact
R&D	Yes, this is military driven development with a high degree of national secrecy, therefore a need for Swedish R&D. In the visible part of the spectrum there might be some civilian technology development to follow.

Conclusions on military utility

There is still a considerable uncertainty in the Fraunhofer assessments of the bio-inspired camouflage technology and the TRL-levels are generally low in the 2030 perspective. There is ongoing development in materials for adaptability also in other than visible wavelengths but the technical readiness for 2040 is difficult to assess from open sources, since development is mainly military driven. In addition, to reach the full potential of adaptive camouflage research, development is needed not only on the "Camouflage organ" but also on the sensing system, the "control organ" and their integration as a system. This development should be guided by the development of tactics, i.e. how to do things differently having this new adaptive camouflage functionality.

"Bio-inspired camouflage" should be viewed in a broad multispectral perspective involving design requirements for low contrast in the visual- and IR-spectrum as well as, for most applications, low reflectivity in the radar-band. There is an ongoing duel between sensor development and camouflage systems and our assessment is that the fewer and more valuable platforms we have, we will need better camouflage performance in order to maintain low probability of detection and short detection distances, at least if faced with a technologically mature adversary. Our overall assessment is that bio-inspired adaptive camouflage systems have significant potential for military utility.

UCAV 2040

Ref: [4]

Introduction

In last year's Technology Forecast[3], the potential military utility of Unmanned Aerial Vehicles (UAV) for SwAF was evaluated and deemed to be significant. However, in that analysis only remotely piloted and unarmed vehicles were considered. Therefore, the primary analysis was on different forms of sensor carrying aircraft. In this review report the focus is on the potential military utility in Unmanned Combat Aerial Vehicles (UCAV) for SwAF. This review is based on the Fraunhofer report: "Unmanned Combat Aerial Vehicles" which gives a brief but thoughtful overview of UCAV today and possible changes and developments required in order to face a more technologically qualified adversary.

The term UCAV is typically used for UAVs carrying some sort of weapon system, whereas in the reviewed report the term is used for UAVs that are: "optimized for tasks in non-permissive airspace, *i.e. aerial combat against other aircraft or strike against defended targets".* This definition excludes most of the existing weapon carrying UAVs and instead focuses on future UAVs that are designed to be deployed as capable fighter and bomber aircraft.

There are two possible options for achieving controlled unmanned flight. The first option is to place a pilot in a ground control station (GCS), remotely controlling the aircraft over a data link. This solution is readily referred to as Remotely Piloted Aircraft System (RPAS). The second option is to make the aircraft independent of continuous human interaction by equipping it with some sort of artificial intelligence (AI) that can make decisions of its own during flight, thus increasing the level of autonomy. What kind of decisions that the AI is allowed to make is however left to a human operator to decide. Most UAVs today are remotely piloted but demonstrations of aircraft that are capable of completing preprogramed missions are available. One example is the autonomous X-47B that has performed carrier-based launch and recovery without direct human involvement (Northrop Grumman, 2014).

In this report the potential military utility of UCAV for SwAF is assessed based on the expected development of UCAV technology by the year 2040 described in [4].

Identified possibilities and constraints

The following technological advantages and disadvantages have been identified by the reviewer from the report and the seminars:

Advantages (compared to manned aircraft)

- Easier to design, since no space or life support equipment for humans are required.
- The space and weight gained by removing the pilot from the aircraft can allow for designs that can improve range, endurance, speed, and/or to reduce signatures.
- Modern fighter aircraft are designed to withstand g-forces somewhat larger than what a pilot is able to endure. If the pilot is removed, aerial vehicles could benefit from a design that lets them withstand much higher forces than current manned aircraft, which in combination with improved maneuverability could improve survivability.

[3] P. Bull, B Persson, L. Löfgren, *Obemannade farkoster*, FHS 2013-06-09.

- Since there is no pilot onboard the risk for loss of own personnel during a mission is reduced.
- Educating fighter pilots is both expensive and time consuming. UCAV pilots will require training, but not to the same extent as fighter pilots, thus reducing the cost for education/training.
- UCAV pilots will not have to fulfil the same high demands as conventional fighter pilots; therefore the recruitment base should be much larger.
- Since future UCAV will be smaller and will not require any accommodation for humans, they will likely be cheaper.
- UCAV pilots fly the UAV from a GCS which likely is a more pleasant work environment than the cockpit of a fighter aircraft. This could have many beneficial effects, but most notably the pilot does not have to fear for his own life during the mission.
- UCAV are disposable as a last resort to a military problem. For example, it could be acceptable to send the UCAV on a mission knowing that it will not have enough fuel to return to base if the success of the mission is worth more than the loss of a the UCAV.

Autonomous (compared to remotely piloted and manned aircraft)

- In some areas computers, with accompanying algorithms, surpass the human brain, whereas in others areas the opposite holds true. Two areas where the computer definitely has advantages are simultaneous capacity and reaction time. A computer can easily manage huge numbers of targets, obtained by radar or other sensors, while receiving information from communication channels and navigation systems. From a human perspective this is perceived to happen simultaneously in a computer. Thus, it could be argued that a future autonomous UCAV could achieve better situational awareness than a remotely piloted or manned aircraft provided that appropriate sensors are equipped.
- The IA of a future UCAV will most likely not have any physiological effect in the decision loop. That is, the UCAV will only focus on completing the current mission, without getting distracted by things that usually concern humans, e.g. moral aspects, fear or stress.
- The combat behavior of a future autonomous UCAV will be preprogramed. If there are indications during or after the mission that the behavior has flaws, the behavior can be replaced by new code, which can be done very fast. In order to change human combat behavior, extensive training is usually required.
- Similarly, human pilots need continuous flight training to maintain their skill level whereas the AI does not. Thus, savings can be made on both reduced wear of the platform and training costs.

Disadvantages (compared to manned aircraft)

- A main concern for UAV in general is enabling secure communication between the RPAS and the GCS. The link is a weakness in the system that can be jammed or possibly even hacked.
- Legal aspects on unmanned violence could be a deal-breaker for democratic countries, even though current users of armed UAVs seem to have overcome this.
- If communications have to be increased, stealth may be jeopardized as the UCAV would be exposed to hostile Electronic Support Measures (ESM)
- The Ground Control Station (GCS) is valuable and likely an easily detectable target

Autonomous (compared to remotely piloted and manned aircraft)

- There is a risk that the behavior of the AI in a UCAV is predictable (since that is desirable from a safety perspective). This can be exploited by adversaries, which is very undesirable.
- AI will not have any judgment; it will simply do what it is told. A pilot on the other hand may question unreasonable orders and would not be so easily tricked by a hacked communication link.
- There are big differences in both moral and legal aspects between RPAS and automated UCAV that select and engage their own targets. For more information on this topic see UN meeting “Lethal Autonomous Weapons” (UN Lethal Autonomous Weapons)
- IA will not have any imagination. It may be that they make better decisions than a human pilot when all information is given but deceit is often a key to success in military operations and IA will have a hard time dealing with that. The reason chess computers outperform human players is not primarily because they conceive elaborate game plans, but rather that they can calculate the outcome of a vast numbers of moves ahead and compare the outcome of different alternative decisions. This is only possible because the number of moves is (although massive) limited. In combat however, the number of possible decisions, counter-decisions, and unknowns are infinite, which is why a UCAV AI will not have the same edge over a human as a chess IA has.

Assumptions

The concept scenarios are based on the following assumptions:

- UAV are integrated into the Swedish civil airspace and are at the same level or better concerning detection and avoidance as regular pilots.
- The UAV is as independent of direction and support from its commander or operator to the same level as a regular manned aircraft.
- Reliable secure short range communication is developed and available to SwAF.

Suggested military use

The following applications are mentioned in the report:

- Manned-Unmanned Teaming (MUT)
- Bomber
- Fighter
- Electronic Warfare (EW)
- Suppression of Enemy Air Defenses (SEAD)
- Intelligence, Surveillance, Reconnaissance (ISR)

Concept scenario in 2040

Description

1. UCAVs are introduced as a part of existing manned JAS 39 Gripen squadrons. The UCAVs would have at least equal stealth properties as JAS 39 and be able to act as any member of the squadron. Communication with the UCAV is mainly performed within the group rather than from a GCS. The UCAVs would carry out the most high risk activities (running the radar or flying closest to the enemy) while benefiting from having humans close by for directions and hard decisions when required. It could also serve as a shield for own members.

The squadron is intended to perform the same tasks as JAS 39 does today, but with the support of UCAV the mission effectiveness is expected to increase since the UCAV can be exposed to higher risk and benefit from improved situational awareness, while many of the downsides that arise from separating the pilot from the aircraft (such as risk for jamming or hacking) are eliminated.

As an example, the technical demonstrator Neuron has demonstrated the capability of flying in formation (although remotely piloted) with other manned aircraft (Defence Update, 2014).

SWOT-analysis

The following strengths, weaknesses, opportunities and threats with the mixed manned-unmanned squadrons were identified at the seminar:

<u>Strengths:</u>

- Traditional strengths from UAV design; see advantages above.
- The improved situational awareness in the UCAV could allow for more coordinated attacks and mustering of strength.
- UCAV has the primary emitter roll and thereby increases manned aircraft survivability
- Fighter pilots are expensive and their training is time consuming. The suggested mix of manned and unmanned platforms would allow for fewer pilots in the organization while maintaining the same operational capability.
- Less vulnerable to jamming (compared to RPAS)
- The suggested teaming would force any opponent to consider two types of threat aircraft instead of just one.

<u>Weaknesses:</u>

- Future UCAV may well outperform modern JAS 39 aircraft concerning endurance, speed, and stealth, many aspects of those advantages would be lost when teamed with a manned aircraft.
- The proposed solution would require two aerial systems, which is costly from many perspectives.

<u>Opportunities:</u>

- The issue with the UCAV's lack of imagination and judgment would be solved since this is transferred to the pilots in the squadron. This assumes that the level of autonomy is on the same level as a human pilot, so that the work load on the human operators is not increased. Another possibility would be to have a two seated manned aircraft where one of the operators is responsible for the actions of the UCAV.
- The greatest advantage of having a mixed unit is that the decision maker is brought closer to the more advanced technology, without interfering with it. Thus, the need for the manned aircraft to be constantly upgraded is reduced since the squadron as a whole would still maintain high mission effectiveness, enabled by the UCAV. This without the need for continuous development of the manned aircraft, which could be operational over a longer time period.
- The UCAV are disposable and may be able to shield group members by attracting launched hostile munitions, thereby improving the survivability of the manned aircraft. The higher level of maneuverability of the UCAV, compared to a manned aircraft, might even result in the avoidance of munition while protecting the manned aircraft.

<u>Threats:</u>

- The UCAV is still not immune to hacking; however there would always be a human pilot in the manned aircraft who could react to such an event.
- The manned aircraft will become a high value target; however it can operate in an electromagnetically silent mode thus reducing the probability of intercept.

Assessed capability impact

UCAVs can contribute to a broad range of capabilities in the SwAF catalogue directly. Since the catalogue is under revision, no specific capabilities are presented apart from the general bullets bellow:

- Capability to affect targets including SEAD/DEAD
- Capability for EW
- Capability to provide geographical, oceanographical and meteorological information
- Capability for intelligence
- Capability to protect objects against attack

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the technology:

Item	**Assessment**
Acquisition cost/ system	Significant, but not necessarily as expensive as a possible next generation manned fighter aircraft
C2 footprint	ACC: significant, Squadron: high, CRC: low if autonomous, high if RPAS
Logistic footprint	At least doubled maintenance due to two different airborne systems
Legalities	Need to be developed
Doctrine/TTP	Significant revisions to enable the full utilization of UCAV
Organization	Introduction of UCAVs could allow for fewer pilots in the organization while maintaining the same operational capability.
Training	Possible need for a new category of personnel. Training required for JAS 39 pilots, technicians, CRC controllers and staff officers The interaction between AI and operators has uncertain implications and could affect the need for training.
Facilities	New maintenance and training facilities
R&D	National industry and research agencies need to develop secure short range communication and sensor-suites that are adapted to military AI. Software for combat AI has to be developed and maintained. General aviation research needed

Conclusions on military utility

The review group is unified in the belief that future UCAV can increase mission effectiveness and survivability if integrated into existing fighter squadrons. From a flight technological perspective most of the knowledge of to construct high performance UCAV already exists and several technical demonstrator UAV have been built and flown at the time of writing. However, reliable artificial intelligence for automated flight and combat has yet to show its full potential in order for the proposed scenario to be realistic.

It is important to keep in mind that if the prediction that UCAV will improve combat effectiveness; it is not only own forces that can utilize this opportunity. Therefore it is important to keep a close eye on the UCAV development regardless of any SwAF intention to acquire UCAV, since future hostile platforms may very well be UCAV. Thus, investigating jamming and cyber security issues that almost all UCAV are subjected to is important for both force protection and as a means of countering future hostile UCAV. Furthermore, it is important to monitor the legal development regarding unmanned and automated violence since legislations can be a deal-breaker for the military utility of UCAV.

Manned flight has had more than a century to streamline the surrounding organizations, whereas UAV has just entered the arena. Therefore, a direct comparison of costs in both money and personnel is not very fair. If the UAV technology enters into civil airspace as a regular actor there will be a much higher incitement to decrease organizational costs, for example one UAV pilot can likely monitor several aircraft (much like an air traffic controller). Also, UAVs already have the inherent advantage of highly reduced pilot training costs and fuel consumption.

If the idea of UCAV that are superior in air combat is realizable we may be facing a paradigm shift of the same magnitude as experienced when airborne radar or air-to-air missiles were introduced. Thus, UCAV are deemed to have potential for significant military utility in future air operations even though it is, at present, hard to predict how they will be used to maximize their military utility.

Reflections on the method

Our evaluation of the method used shows that there is a risk that the assessment is biased by the participating experts' presumptions and experiences from their own field of research. The scenarios that were chosen do not cover all aspects of the technology and their possible contribution to operational capabilities. It should be stressed that we have assessed four technologies' potential military utility in the presented scenarios, not the technology itself.

The chosen definition of military utility clearly affects the result of the study. The definition is the same that was used in the Technology Forecast 2013. It is believed to be good enough for this report, but could be further elaborated in the future.

The greatest value of the method used is its simplicity, cost effectiveness and the tradeoff that it promotes learning within the working group. The composition of the working group and the methodology used is believed to provide for a broad and balanced coverage of the technologies under study.

This report provides executive summaries of the Fraunhofer reports which are believed to help the SwAF Headquarter to evaluate the military utility of emerging technologies within identified relevant scenarios.