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NATO ARMY ARMAMENTS GROUP (NAAG)

JOINT CAPABILITY GROUP VERTICAL LIFT (JCGVL)

Next Generation Rotorcraft Capability

Final Report

(LAMP Reference: VL-001)

1. Please find attached the Next Generation Rotorcraft Capability (NGRC) Final Report for information in preparation for the upcoming JCGVL meeting on 19-20 September 2018. This report was developed by the NGRC Team of Experts.

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1 Enclosure

NATO Army Armaments Group

Joint Capability Group on Vertical Lift

Next Generation Rotorcraft Capability Team of Experts

Final Report

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Preface[1]

Today's changing strategic threat and smaller defence budgets are effecting how multinational forces will work and fight together, as well as share intelligence, surveillance, target acquisition, and reconnaissance (ISTAR).

During the first 17 years of the 21st Century, military action by western oriented forces can largely be defined as asymmetric counter-insurgency (COIN) type deployments, with some obvious exceptions including the retaking of Iraq in 2003. However, fighting has largely not been peer-to-peer and dominance of the air domain has nearly always been assured, or quickly asserted.

However, Russian military action in Georgia, the Ukraine and Syria has served to alert nations who escaped from the Soviet sphere of influence post-Cold War that they may once again be under threat, particularly from covert Russian attempts to destabilize such countries as a pre-curser to some form of military invasion.

In Asia, the People's Republic of China has been increasing not only the strength of its forces but is also expanding its geographic sphere of influence into the South and East China Seas, as well as smaller incursions such as the recent stand-off between Indian and Chinese forces in Bhutan.

The threat of a near-peer, linear conflict has meant a return to the possibility of large multi-national force deployments and operations, which would be particularly important in meeting national political requirements. Defence cuts have also made it difficult for individual western styled forces to act alone.

In terms of military helicopter operations, more than ever there is a need to be interoperable with other nations.

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[1] Andrew Drwiega, DefenceWorX, Ltd

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Executive Summary

At the February 2016 meeting of NATO Joint Capability Group on Vertical Lift (JCG VL) a Team of Experts (TOE) group was authorized with a mandate to identify, in two-years, a Next Generation Rotorcraft Capability (NGRC) for 2035 and beyond. The initial meeting was held at the NATO Joint Air Power Competence Center (JAPCC), Kalkar, Germany on 13-14 July 2016. The TOE was comprised of representatives from NATO agencies (JAPCC, Allied Command Transformation-Staff Element Europe (ACT-SEE), NATO Science and Technology Organization (STO), and NATO Industrial Advisory Group (NIAG)) as well as national representatives from the United Kingdom and United States.

The missions identified in NATO Standard ATP-49[2] and augmented with maritime missions were the baseline for the future operational needs in this assessment (Appendix A).

The intent of this assessment is to inform nations and create support to develop a draft NATO Staff Requirement (NSR) by JCG VL leading to the development and fielding of next generation rotorcraft by nations. This assessment will also contribute to the NATO Defense Planning Process (NDPP) Rotorcraft Long Term Assessment and Long Term Capability Requirements.

The future operating environment will consist of challenges due to emerging technology, threat system capabilities, economic realities, geographic conflict locations, and adverse flight environments.

The NGRC TOE concluded that current Alliance rotorcraft will reach the end of their programmed life in the 2035-2045 time period and will need to be replaced. Technology has rapidly advanced and proliferated, thereby reducing or eliminating the Alliance's operational overmatch capability when faced by a Peer Nation or advanced asymmetrical threat. To mitigate this situation, investment now in applicable advanced technologies is required to ensure technical maturity to meet program design and development schedules. Long system acquisition lead times dictates that Next Generation Rotorcraft programs must be initiated now.

The NGRC TOE recommends JCG VL immediately establish an Ad Hoc group of interested nations to further develop and endorse one or more Next Generation Rotorcraft NSRs by 2020. To accelerate progress a generic draft Next Generation Rotorcraft NSR has been developed and is at Appendix E. The TOE also recommends nations establish funded domestic programs or multi-national cooperative programs, beginning with the drafting of the appropriate type agreement(s) in parallel to developing the final NSR.

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[2] NATO Standard ATP-49, "Use of Helicopters in Land Operations", Edition G, Version 1, March 2016, page 1-8.

1.0 Vision:

Vertical lift aviation is a fundamental enabler of military operations, executing a vast array of missions. Optimally as an enabler, vertical lift capability would be fully available and flexible – available to conduct the mission required, when required, in the environment and manner by which it is required and flexible to adapt to the situation when necessary. The current NATO vertical lift assets are not capable of that level of availability or flexibility. Since its origin, military vertical lift capability has greatly improved in aspects such as payload capacity, flight performance, and mission equipment; however, it is becoming increasingly inefficient and ineffective to improve aircraft designs from the 1960-70 era. Furthermore, a significant portion of NATO national fleet of rotorcraft will approach the end of their programmed life in the 2035-2045 time period.

Inherently, there are three operational constraints to vertical lift capability, they are: the lacks of a crew to conduct the mission, aircraft not mission capable and limiting environments. If these three constraints were removed such that the full capability of vertical lift were always available in the manner needed, the effect on military operations would be significant and would change the paradigm of constrained operations that exists today. No longer would the weather have to be good to conduct a mission. No longer would an operation be delayed only to then be canceled or not completely accomplished because the aircrew was past the allowed duty day. No longer would sustained military operations be degraded because the high tempo caused the aviation assets to be broken or in a scheduled maintenance process. This vision is obtainable in next generation rotorcraft with the substantial advancements in technologies and ‘clean sheet’ designs. For example, an aircraft can be designed and integrated for fully autonomous or optimally crewed operations; thereby, expanding the ‘duty day’ of the aircraft and crew. Advanced flight controls and mission equipment can enable not only fatigue free flight and therefore reduced maintenance downtime, but also allow seamless operations in degraded visual environments and austere conditions with reduced pilot workload. Platforms and the digital backbone can be ‘born’ modular to allow flexibility and rapid upgrade to overcome ever changing environments and demands. The NGRC TOE assessment is that ‘clean sheet’ designs are required to fully realize this vertical lift capability, availability, and flexibility required in future military operations.

This report outlines the details and a roadmap for enabling that vision across the NATO rotorcraft fleet by taking full advantage of the substantial advancements in technology. Some NATO nations are already taking huge steps toward next generation, new design rotorcraft; maintaining NATO interoperability in this critical military enabler is vital. The NGRC TOE recommends development of NSRs and for nations to invest in the technology opportunities presented in this report to ensure NATO interoperability in, and dominance through vertical lift capability.

2.0 Introduction:

In 2016 JCG VL recognized that Alliance's rotorcraft fleet was aging and would reach the end of their programmed life in the 2035-2045 time period. JCG VL also understood technology advances were evolving rapidly that had the potential to significantly alter the design and development philosophy of a future fleet of rotorcraft. Based on historical experience, the design, development, production and fielding of a future rotorcraft have taken up to 20 years.

Recognizing the obsolescence date of the current rotorcraft fleet and the lead-time to field a new capability, JCG VL established the NGRC TOE. To expedite the process, the TOE was composed of representatives from several NATO agencies and interested nations[3]. This NGRC TOE Final Report includes as an Appendix, a draft NATO Staff Requirement for consideration by JCG VL and nations as they address the pending capability gap.

This report comprises four major sections, Fleet Life Expectancy, Future Operating Environment, Next Generation Capability, and Technology Enablers. The Executive Summaries from two key supporting activities, the NATO Industrial Advisory Group (NIAG) Study Group-219 Final Report and the NATO Science and Technology Organization (STO) AVT-ST-005 Final Report are attached as appendixes. These groups were established to support the TOE and provided significant input to this report.

3.0 Fleet Life Expectancy

In the 2035-2045 timeframe a majority of NATO's helicopters will reach the end of their programmed life and will be due for replacement. Appendix B highlights this problem graphically by identifying the NATO helicopter types and their likely out-of-service dates. The data for this table was obtained from open sources, as well as industrial reports addressing Next Generation Rotorcraft Capability. The table shows many NATO nations will need to replace their rotorcraft capability, both for the land and maritime environment, unless they are prepared to expend considerable economic resources on extending the useful life of their platforms, while at the same time enhancing the platform capability and survivability. Most NATO countries have, or are planning to reduce the number of aircraft types they operate, and this is expected to continue. By taking advantage of current and evolving technology, multirole modular platforms can be available in the time period of interest; thereby, addressing nation's fleet size, operational capability, economics and obsolesce issues. A rare opportunity exists now for shrewd investment by nations to dramatically reduce a range of future costs.

4.0 Future Operating Environment

The operating environment is changing rapidly, forcing NATO to develop solutions to effectively confront an ever-larger range of challenges, threats and potential

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[3] ACT-SEE, JAPCC, NIAG, STO, United Kingdom and the United States.

adversaries. Major strategic analysis reports[4] [5] [6] have provided the Alliance leadership with a vision into what those challenges might look like and how the Alliance's capability might be affected.

In theory Alliance forces are required to be capable of operating at any location in the world under various climatic and geographical conditions. However, in reality the future rotorcraft capability will need to be tailorable to fit both the Alliance's expectations as well as national realities. The Alliance must have the capability to conduct operations ranging from peacetime military operations to high intensity conflict against peer and near peer nation threats, while being capable of effectively reacting to adversaries using asymmetric tactics. Small aviation units will be required to operate independently in a Theater of Operations for extended periods, which may require the conduct of multiple types of missions, as identified in ATP-49 (Appendix A), with little or no outside support. In addition, the Alliance rotorcraft will have to be networked not only between themselves and team elements, but also with the theater units being supported. Thus requiring a significant command and control communications capability.

Several distinct trends and their associated levels of risk and uncertainty are shaping the future operating environment, to include technology advancements, the threat, resource scarcity, global economic activity, demographics, rapid urbanization, climate change, and social change. Four of the key future operating environments are further amplified below.

a. Global Economic Activity. Globalization and the digital age have radically changed the economic environment since 2000. The European Union (EU) has a sizeable Gross Domestic Product, but is fragmented and focused more on domestic economic activities and social programs than on maintaining and supporting a strong centralized military capability. The NATO Alliance is responsible for the defense of Europe, but because the Alliance is an organization of 29 nations today, with each nation retaining political and economic national sovereignty, it may be difficult to develop and field a meaningful future rotorcraft capability. Next generation rotorcraft may be unaffordable for a single nation due to anticipated costs of the high technology platform. As a result, most nations may need to establish a collaborative or cooperative development program or procure their rotorcraft assets from another country.

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[4] NATO (SACT) (2013) *Strategic Foresight Analysis 2013 Report*. Norfolk, Virginia USA: NATO Headquarters Supreme Allied Command Transformation.

[5] NATO (SACT) (2015) *Strategic Foresight Analysis 2015 Interim Update to the SFA 2013 Report*. Norfolk, Virginia USA: NATO Headquarters Supreme Allied Command Transformation.

[6] Ministry of Defence (2014) Strategic Trends Programme, *Global Strategic Trends – Out to 2045, Fifth Edition.* London, UK: Ministry of Defence.

b. The Threat Environment. To operate and survive in a high intensity hostile environment, the platform will have to be equipped with an advanced autonomous operating "Defensive Aids Suite" (DAS), that incorporates high definition sensors capable of detecting and neutralizing the threats postulated for the 2035+ time period. Navigation systems will have to be designed to provide the required information in a GPS-denied environment and when mission management systems cannot be connected to a central network. The future rotorcraft should be designed to operate and be maintained in a CBRN environment. Vital elements of the platform must have ballistic protection to counter kinetic impacts. Mission system redundancy will be required for critical platform subsystems to ensure mission success. The proliferation of commercially available Unmanned Aerial Systems (UASs) of different size and type is also anticipated to enlarge the threat spectrum against battlefield rotorcraft, especially when used by non-conventional adversaries as part of their asymmetric tactics.

Threats Faced by Future Rotorcraft
-Air Defense
-Guided Anti-Tank
-Field Artillery
-RPG
-Helicopter Mines
-Direct Energy Weapons
-Aerial Platforms
-UASs
-EW and Cyber attack
-CBRN

c. Geographic Environment. Analysis indicates that military operations will become more routine and demanding in three specific geographic domains: the Artic, maritime and littoral regions, and urban areas. Each of these represents unique challenges to existing rotorcraft and point toward the need for NGR. Aforementioned NATO strategic studies have stated that NATO has to be prepared to take actions practically anywhere in the world under various climate conditions. As Arctic ice melts and the North Pole area becomes more accessible, it also increases the potential for territorial ambitions of regional nations due to a large abundance of untapped oil, natural gas and fresh water reserves. The Arctic exhibits extreme cold, snow and unique navigation and visual conditions that challenge existing rotorcraft. Among geographical conditions, the maritime and littoral environment deserves special attention because today 80% of the world population lives within 100 miles of the coast and 90% of the world's commerce is seaborne with 75% of that trade passing through a few vulnerable canals and international straits. The world's oceans and seas are an increasingly accessible environment for transnational criminal and terrorist activities, including the illegal trafficking of humans, narcotics, piracy, weapons and associated materials. The Anti-Access/Area Denial (A2/AD) capabilities of the coastal states are increasing. There is also an increase in the overall inventory of submarines, amphibious assault ships with large flight decks and increased rotorcraft capabilities. The effects of sand, salt, water, degraded visibility and shipboard compatibility for afloat transport, operation and maintenance will stress existing rotorcraft designs and require NGR. The growth of the world's population will give rise to large urbanized territories. This in turn will demand dramatically new operations in the extremely complex multi-layered and multi-faceted megacity environment. Adversaries will leverage the "benefits" that megacities offer in reaching their objectives. Densely populated urbanized areas will be a complex and congested operational environment for rotorcraft, their operators and users. To facilitate operations in this very complex three-dimensional battlespace, platforms must be equipped with sensors and devices for seamless situational awareness. Special attention must be given to the avoidance of collisions with natural as well as artificial obstacles, as well as the increased number of users of the third dimension. Advanced aircraft maneuverability and agility will be key to survivability in the urban battlefield. History has demonstrated that rotorcraft must be capable of operating in extreme environments such as high temperatures, high altitude and dusty, sandy locations.

d. Technology Environment. Technology has been advancing at an accelerated rate throughout the world. As technology proliferates, the quantity and effectiveness of potential adversaries' capabilities have also increased, to the point where NATO nation's operational advantage may no longer exist. Operations will require robust and timely data sharing with backup options in case of operations in electronically degraded or denied environments. It is anticipated that for certain roles and missions future rotorcraft may be optionally piloted. Technology will support advances in rotorcraft performance: higher speed, longer range, extended loiter time, larger payloads, operations at higher altitudes, as well as operations in degraded environments. Advancements in support technologies will reduce sustainment costs, reduce logistics footprint, enable modularity and the potential to improve and sustain independent operations.

5.0 Next Generation Capability:[7]

The next generation of military rotorcraft must be effective and survivable in the future operating environment, technically viable, and economically affordable. They must be significantly more available and flexible than the current NATO rotorcraft fleet to overcome the limitations already explained. Increasing NATO interoperability using established doctrine, tactics, techniques and procedures is possible through development of foundational next generation requirements and design approaches.
Bold and innovative system-level approaches such as modularity, multi-level capability, and Condition Based Operations (CBO), maximize interoperability between platforms and nations, reduce life-cycle costs for new mission capabilities and upgrades, enhance reuse of components, and optimize life-cycle supportability. For this innovative NGR approach to be successful, well documented interfaces and standards across all stakeholders will be necessary recognizing the significant cultural changes in

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[7] The information contained in this section was extracted from the draft Generic NATO Staff Requirement for a Next Generation Rotorcraft (Appendix E).

requirements, acquisition, business models, and regulatory approval required. Leveraging smart platform integrated modular architectures for avionics, mission systems, propulsion, electrical power, and structures in a NGR design will enable the “plug and play” of mission-associated modules and nations to tailor the system to their national needs through the procurement of national specific mission capability modules while achieving the economy of scale in production and common logistics support. Together these capabilities will blur/combine/align acquisition and support approaches. Applying these ideas and features at the system level on a broad scale at the outset of requirements generation and conceptual design represents a paradigm shift in approach, with technical, regulatory and industrial base implications. However, this NGR approach will enable dramatic operational, acquisition and sustainment flexibility with significant through life cost savings and efficient ‘rolling/spiral upgrades’.

Next generation rotorcraft can significantly enhance military effectiveness and operational capability. Those capabilities will only be realized by investment in high payoff technology and new vehicle design. Increased flight efficiency and performance is achievable in NGR to enable larger payloads over longer unrefueled ranges at greater speed and in more demanding conditions without sacrificing agility or maneuverability. Risk in complex, stressing atmospheric, adverse and high threat environments can be reduced by NGR thru integrated and off-platform survivability, inherent hands-free or augmented flight in degraded visual environments and limiting pilot workload. Significantly higher performing rotorcraft offer the potential to reduce force structure such as a less than one for one replacement ratio even while increasing operating tempo during sustained campaigns and removing the requirement for forward refueling. Additionally, a longer-range platform provides for self-deployment from the NATO nation to most areas of operation, thereby freeing up strategic movement assets. A NGR enhances the combined arms deep fight by orchestrating advanced teaming of manned and unmanned systems and long range fires thru advanced and integrated networking and communications.

Challenges do exist to realize these NGR capabilities. Examination of the CBO concept must be accomplished to evaluate value and assess feasibility. NATO needs to leverage regulatory culture changes occurring and embark on positively influencing them. Direct energy weapons must be explored as both a capability (offensive/defensive) and a threat. Hybrid propulsion represents the next leap ahead in performance and must be matured quickly for reduced emissions/signatures and high-power payloads. NATO needs to be aware of the requirements for future Precision Based Navigation (PBN) airspace regulations to operate in peacetime, as reliance on waivers will be unsustainable. NGR must be designed for the denial of space-based precision navigation and time capabilities during conflict.

This TOE assessment identifies disruptive capabilities for NGR generic to all missions and size points to exploit rapidly evolving technology in the context of global trends and aerospace industry-wide initiatives. This collective section of NGR capabilities are captured in the generic (no specific size or mission) draft NSR at Appendix E.

6.0 Technology Enablers

Introduction of advanced technologies into future rotorcraft designs will introduce significant enhancements in mission capabilities. The benefits are likely to arise from adoption of a single major enabling technology (e.g. the improved performance and reduced noise/vibration possible with morphing rotor technology). While incremental technical improvements will yield progressive increases in operational capability, the focus of this effort was on technology drivers that will permit step changes in future rotorcraft capabilities. Early identification and quantification of technology investments provides an opportunity to accelerate development, maturation and transition of high value S&T enablers for next generation military capabilities.

The NGRC TOE leveraged parallel NATO activities from the Science and Technology Organization (STO) and the NATO Industrial Advisory Group (NIAG). These efforts focused on identifying those technologies that are expected to be the key enablers to developing future rotorcraft capabilities.

- STO Applied Vehicle Technologies (AVT) Panel: Specialist Team (ST) 005 - Future Rotorcraft Technologies. https://scienceconnect.sto.nato.int/apps/16873
- NIAG Study Group (SG) 219 - On Concepts for Operations and Equipment for Next Generation Vertical Lift Operations (or "Next Generation Rotorcraft Capability"). https://diweb.hq.nato.int/niag/Pages/StudiesFinalReports.aspx

Consolidation of the outputs from the final reports from AVT-ST-005 (6 June 2018) and NAIG SG 219 (30 April 2018) led to the following key enabling technology categories being identified as primary drivers, these are:

- Flight Control and Performance
- Avionics and Mission Equipment
- Human Factors
- Materials and Manufacturing
- Teaming
- Survivability
- Lethality
- Cost of Ownership

For each of the key enabling technology categories a number of specific technologies are identified. An assessment of their current Technology Readiness Level is made together with a projection for when it will mature to TRL 6[8], a rudimentary prediction of funding required to achieve TRL 8-9 and an assessment of the technology's impact on operational capabilities.

The tables contained within the individual key enabling technology category sections use a common color-coded key for the various attributes, these are:

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[8] System prototype demonstration in a relevant environment at a relevant scale

Current TRL	
🟦	Flight Qualified, TRL 8-9
🟩	Demonstration, TRL 6-7
🟨	Development, TRL 3-6
🟥	Concept, TRL 1-3

Predicted Date for TRL 6	
🟦	Already at TRL 6
🟩	<2025
🟨	2025-2030
🟥	>2030

Maturation Cost (TRL 8-9)	
🟦	<€50m
🟩	€50m-€250m
🟨	€250m-€500m
🟥	>€500m

Capability Impact	
🟦	Very High
🟩	High
🟨	Moderate
🟥	Low

Identification, selection, prioritization and resourcing of technology investments will need to be driven by military capability needs for the next generation of rotorcraft. This will occur in association with changes to the relevant Doctrine, Organization, Training, Material, Leadership and education, Facilities, and Policy (DOTMLPF-P). This report addresses the key technologies envisioned to enable next generation rotorcraft material solutions to achieve the requisite capabilities. Changes to the resourcing profile of a specific technology investment will influence its projected maturation timeframe. Note that the initial estimates of cost to mature and integrate technologies, and the performance enabled, are intentionally conservative to account for risk with only the cursory level of exploration to date.

Flight Control and Performance: Potentially the biggest difference between current rotorcraft and those predicted to enter service in the 2030s is the ability to travel greater distances at significantly higher speeds. The benefits associated with tilt rotor configurations, compound designs and, to a lesser extent, advanced rotorcraft with variable speed transmissions will lead to cruise speeds up to 250kts (and potentially faster in the case of tilt rotor, tilt wing and other advanced VSTOL designs) although clearly there will be a trade-off between speed, range, cost of ownership, payload, etc. These designs offer additional degrees of freedom that can result in multiple solutions for the same basic requirement.

All future rotorcraft designs are expected to exploit Fly-by-Wire (FBW) technology in the medium term with a potential move to Fly-by-Light (FBL) during the late 2030s. The principal benefits will be to improve dynamic performance, increase agility whilst reducing the power requirement at a given cruise speed and to enhance mission safety, reduced pilot workload and sustainment. Key enabling technologies of an Active Flight Control System have already achieved an appropriate level of development for embodiment by 2035 or will do so in the near future. These technologies also contribute to the development of unmanned or optionally piloted platforms.

Key enabling Technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Advanced Inceptors/ Active Control	🟩 2-7+	🟦	🟦	🟩	Examples are in service, new capabilities under development.
Fly-by-Light	🟨 4	🟨	🟩	🟨	The requirement for high data transfer rates & immunity to EM would accelerate development.
Advanced Rotor Technologies	🟥 2-3	🟥	🟨	🟩	Includes variable twist/geometry blades & novel rotor hub designs.
Variable Speed Drive / Rotor Systems	🟨 4	🟨	🟨	🟩	Progression from limited to wide range of variation in speed.
More Electric Aircraft / Electric Power Management	🟨 3-4	🟨	🟥	🟩	Electrically powered actuation systems & electrical intensive aircraft architectures.
Advanced Engine Technologies	🟨 3-5	🟨	🟥	🟩	Hybrid power system mixing conventional and electric technologies with energy storage
Verification Policy for Adoption of Novel Tech.	🟨 5	🟨	🟦	🟩	Formal policy & guidance yet to be released.
Advanced Rotorcraft Configurations (Tilt Rotor & Compound	🟦 4-9	🟦	🟥	🟦	Variable based on similarity to in service & developmental aircraft.

<u>Avionics and Mission Equipment</u>: The performance of future rotorcraft will be increasingly driven by the complexity of the hardware and software interfaces. The ability to rapidly integrate new functionality into the architecture will provide a tactical advantage. This capability can be exploited by the wide application of open architectures providing a route to a viable "plug and play" capability requiring new standards, tools and techniques.

A key area of development is the integration of data from multiple sources to provide enhanced situational awareness to the crew. High fidelity, low latency sensors will allow operations to be routinely conducted in severely degraded environments providing a high degree of operational advantage over adversaries that are not so equipped.

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Standards for representing the architecture & components	2-7+	🟨	🟦	🟨	Current maturity level of applicable standards & tools varies widely.
Virtual integration & Verification of models	2-5+	🟩	🟦	🟨	Initial limited domain analysis capability. Increasing capability impact with inclusion of domains
Automated code generation & proving technologies.	2-3	🟨	🟩	🟦	Moderate confidence level of generated code.
Integrated development & analysis environment	3-4	🟨	🟦	🟩	Functional environment based on standards.
Modular reconfigurable mission systems	4	🟩	🟩	🟦	Provides a route to incremental qualification & certification. Supports adoption of CBO.
Dynamic Mission Management (AI)	5-6	🟨	🟩	🟨	Cooperative operations with multiple wing men
Multi-vehicle & multi-sensor fusion	6	🟩	🟩	🟩	Challenge is complexity, current dependence on specific sensors.
Flight in Degraded Visual Environments	6	🟩	🟩	🟦	Situational awareness and control during range of DVE conditions
Precision Navigation & Time Systems	3	🟩	🟩	🟦	Guaranteed during operations in denied/spoofed environments.
Network DAS & Intelligence (AI)	4	🟨	🟩	🟩	Wide Band Satellites should be considered (see also SG-211).

<u>Human Factors</u>: Integration of human factors must be addressed early during the requirements and design processes to increase operational efficiency, increase mission effectiveness, and lower pilot / support workload. Aircraft design is not only a matter of physics based components but also the physiologic and psychological interface. Human System Integration issues are central in this area, but they are also at the heart of major issues in the areas of defense for surveillance using multi-source information systems.

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Measurement of human behavior during flight (biometric data, cognitive states)	🟧 5	🟧	🟩	🟧	Early flight-testing for measurement of behavior kinematics to take place in 2018.
Enhanced fidelity flight simulation providing training closer to real mission conditions.	🟧 3-6	🟥	🟦	🟩	Fidelity of simulators is increasing. The potential to reduce flying hours and hence fleet sizes should be a long-term aspiration.
Sensory cues: auditory, visuals and tactile (augmented reality)	🟧 4	🟧	🟦	🟦	Progression from federated cues to integrated natural type of sensory cueing.
Cognitive Decision Aiding and Making Agents	🟧 5	🟧	🟩	🟩	Required for HMI optimization but challenge is certification for non-deterministic systems.

Materials & Manufacturing: Advances in materials and manufacturing technologies are expected to have a significant impact on the development of future rotorcraft. Fabrication requires a wide range of tools, techniques, processes, procedures and standards in accordance with carefully constructed methodologies. It is highly likely that by 2035 the local manufacture of many spare parts using additive processes will be widespread and many of the currently perceived certification issues will have been addressed. Typically, the maturity of materials and manufacturing technologies is defined in terms of either their TRL or MRL (Manufacturing Readiness Level).

Key enabling technology	Current TRL/MRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Smart (Active) Materials	TRL 3-5	🟧	🟥	🟨	Some technologies are close to lab scale demonstration; a fully certified & airworthy implementation requires significant effort.
Advanced Manufacturing Processes	TRL 6-7	🟦	🟩	🟦	Automated and digital thread capability allows for efficient assembly and life cycle management.
New Manufacturing Technologies	MRL 1-2	🟥	🟥	🟩	Technologies are mature but field manufacturing of certified, airworthy, primary components rely heavily on the advancement of other relevant technologies.
Modeling Analysis & Verification Techniques	MRL 1-3	🟧	🟩	🟧	This is considered to be a critical area that has a significant impact on the maturity of other materials & manufacturing technologies.
Improved/Advanced Materials	TRL 2-4	🟧	🟥	🟨	Maturity will advance rapidly as soon as “modeling, analysis & verification” technologies regarding new materials reaches TRL 6.

Teaming

The ability for a diverse fleet of platforms to work collectively sharing information between them has long been recognized as a “force-multiplier”. In recent years there has been increasing emphasis in advanced teaming with a range of Levels of Interoperability (LOI):

- LOI 1: Indirect receipt/transmission of UAS payload data
- LOI 2: Direct receipt/transmission of UAS payload data
- LOI 3: Control of the UAS payload, not the flight unit
- LOI 4: Control of the UAS without takeoff and landing
- LOI 5: Control of the UAS with takeoff and landing

Current systems tend to be limited to LOI 2 or 3 with higher levels on the point of entering service. It is likely that by 2035+ LOI 4 will be commonplace and require interoperability with multiple unmanned systems. JCG VL has sponsored a new NIAG study focused on rotorcraft Advanced Teaming. This is an important enabling technology.

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Advanced Teaming: Technologies for Workload Reduction	🟧 4	🟧	🟧	🟩	Includes innovative HMI, AI, deep learning, neural network solutions.
Optionally Manned Rotorcraft (i.e. crew of 2, 1 or 0 persons)	🟧 6	🟦	🟧	🟦	Control ranges from manual to full autonomy. Crew becomes a module. Very high certification burden for transport of passengers.
Teaming: Interoperability, Communication Technologies	🟧 5	🟩	🟧	🟦	Requires a significant effort to integrate multiple technologies (both current and projected) into a single NATO-wide unified network.

Survivability: Highly capable and integrated threat systems pose a significant risk to rotorcraft. Survivability requires a systems level approach to mitigate or disrupt the ability of threat systems to execute the kill chain (e.g. detect, acquire, track, ...). This promotes the capability to fly and fight in a complex and contested environment. Survivability will also be supported by key enabling technologies identified in other areas including flight in DVE, dynamic mission management, human factors, and other items contributing to platform capability and pilot effectiveness. Countering the rapidly evolving peer nation threats will require significant investment in technologies to retain operational over match. Key technologies include:

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Multi-Spectrum Signature Control	1-9	🟨	🟥	🟦	Acoustic & Radar signatures expected to mature by 2025-30. Visual & IR signature technologies already in service, full maturity predicted by 2035.
Defensive Aids Systems – Sensors & Effectors	3-9	🟦	🟥	🟦	Requires constant updates to remain operationally relevant.
Defensive Aids – RF Jammers	5	🟨	🟨	🟦	Expendable Active Decoy for RW unlikely before 2030.
Hard Kill Systems (Directed & Kinetic Energy Systems)	3-6	🟨	🟥	🟩	Developmental KE systems widely deployed on land platforms.
Automated Threat Response (AI)	5-6	🟨	🟩	🟩	Requires Modularity to adapt to emerging threats.
STANAG 4781 (NATO Defensive Aids Systems)	5	🟩	🟦	🟦	Planned to issue in 2020, full adoption will be later.
Fire & Explosion Protection	3-9	🟥	🟩	🟩	Mitigation of Hydrodynamic shock is complex issue.
Light Weight Armor (Opaque)	9	🟦	🟦	🟨	Materials are mature although cheaper/lighter less likely solutions under development.
Light Weight Armor (Transparent)	3-6	🟨	🟩	🟨	Some materials currently entering service in niche applications.
Increased Crashworthiness	9	🟦	🟦	🟨	Terrain avoidance systems in service. Improved crashworthy troop seats expected to be adopted in next 10 years.
Cyber	2	🟨	🟥	🟩	Defensive & Offensive.

Lethality

The study undertaken by the STO Specialist Team did not consider weapon effectiveness as a primary driver for platform design although it will clearly be a key attribute for an offensive capability. One specific area where a new capability could be adopted is the adoption of viable airborne directed energy weapons. In June 2017, the US Army reported the first successful trial of a directed energy weapon on AH-64 Apache, a principal benefit being the ability to increase the weapon load.

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Offensive Directed Energy Weapon (DEW)	🟧 5	🟥	🟥	🟩	May require a dedicated platform due to high on-board energy generation requirement. Fielded Airborne system will require significant development.

Cost of Ownership: Reducing the cost of ownership will require changes in fleet management, reduction to the logistics footprint, and modernization of platform sustainment philosophies. At present, 70% to 80% of the total ownership cost of an aircraft relates to in-service operations and maintenance. A suite of technologies will be needed supporting interrelated design, airworthiness certification, and sustainment. The key enabling technologies are expected to include wide use of Health & Usage Monitoring Systems (HUMS) and in particular the exploitation of data gathered by these systems to support the adoption of a Condition Based Maintenance (CBM) and Condition Based Operation (CBO) philosophy. CBO is dynamic planning and deployment decisions based in real time cognitive system and component, capability, status and conditions.

Key enabling technology	Current TRL	Predicted Date for TRL 6	Maturation Cost (TRL 8-9)	Capability Impact	Remarks
Air Vehicle Modularity	🟥 3	🟥	🟥	🟩	Critical Technology for CBO.
HUMS & Data Exploitation	🟩 6-9	🟩	🟦	🟦	HUMS widely adopted but exploitation of data is limited.
Prognostic & Condition Based Maintenance (CBM)	🟧 3-5	🟧	🟦	🟦	Analysis indicates that major benefits can be gained from adoption of prognostic tools.
Condition Sensing of Equipment & Sub-Systems	🟦 8	🟦	🟦	🟦	Enabling technology for Prognostic & CBM.
Predict condition of all equipment and sub-systems prognostics	🟥 3	🟧	🟩	🟦	Enabling technology for Prognostic & CBM.
Development of Improved Predictive Tools for derivation of safety factors, operational use, etc.	🟧 3-7	🟧	🟩	🟩	Tools widely available within S&T community but less mature in tactical organizations. Further development required for these tools to provide a robust alternative to physical inspection.
Systems Reliability Enhancement	🟧 4-7	🟧	🟦	🟩	General reliability of systems increasing. Data analysis is required to identify areas where maintenance could be relaxed.
Increased use of Performance Based Contracting	🟧 3-9	🟩	🟦	🟦	Arrangements are becoming commonplace to offer significant potential benefits.

7.0 Conclusions:

- The threat has evolved and places the NATO rotorcraft fleet at risk of capability overmatch today.
- Failure to act now significantly increases rotorcraft risk of operational survivability and effectiveness and NATO interoperability.
- Significant numbers of Alliance rotorcraft will reach the end of their programmed life in the 2035-2045 time period and will need to be replaced.
- Technology has rapidly advanced and proliferated. Enhanced rotorcraft capability is required to counter peer nation or advanced asymmetrical threats.
- Investment in applicable advanced technologies is required now to ensure mature technology is available to meet program design and development schedules.
- The long system acquisition lead-time requires the initiation of next generation rotorcraft programs now
- Enhanced platform performance at reduced Life Cycle Cost and force structure, eliminates the need for one-to-one platform replacement.
- Regulatory and Airworthiness authorities (military and civil, FAA/EASA) need to facilitate understanding and acceptance of modularity and rapid re-configurability to achieve common standards.
- Development of standardized, cyber-secure open modular architecture standards and processes must be accelerated.
- Use of unmanned platforms can replace some manned platforms in the period of interest.
- Multirole tailorable platforms supported by advanced logistics concepts will result in an enhanced level of operational availability.
- National next generation rotorcraft program cost could be reduced through the implementation of collaborative or cooperative type programs.
- New operational concepts are required to be written that leverage next generation platform capability and performance.
- New Tactics, Techniques and Procedures are required to optimize the advanced modular rotorcraft capability.
- Advanced Teaming operational analysis and flight demonstrations need to be conducted.

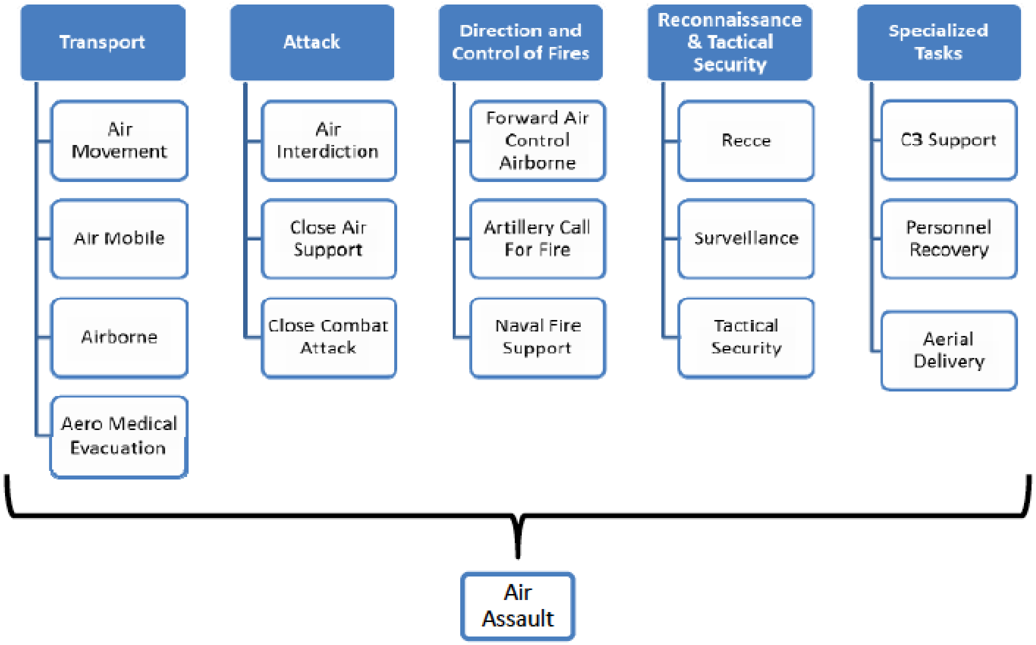
8.0 Recommendations:

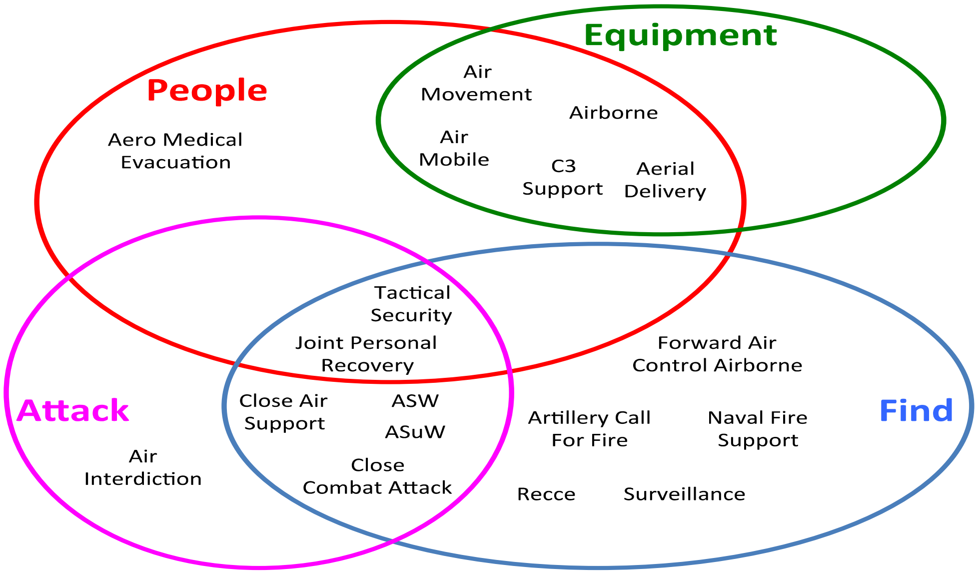
- JCG VL establishes an Ad Hoc group of interested nations to further develop Next Generation Rotorcraft NATO Staff Requirements (NSR) by 2020.
- Nations establish domestic programs or multi-national collaborative or cooperative programs under the appropriate type agreement(s) in parallel to the development of NSRs.
- Nations program resources now to support the development of next generation rotorcraft technology and initiation of acquisition programs.

- NATO and individual nations invest in identified critical and high payoff technologies to enable and enhance next generation rotorcraft capabilities.
- NATO and nations develop and deploy hardware and software interface standards enabling next generation rotorcraft mission systems, structures and propulsion to be “born-modular.”
- This assessment is utilized in the appropriate NDPP cycle to identify the requirement for an interoperable NATO next generation rotorcraft capability.
- NATO and nations evolve new Tactics, Techniques and Procedures and operational concepts that take advantage of next generational rotorcraft capabilities.
- Advanced Teaming flight demonstrations be conducted to provide the analytical basis for advanced operational concepts.

Appendix A

NATO ATP-49 Rotorcraft Missions





Appendix B

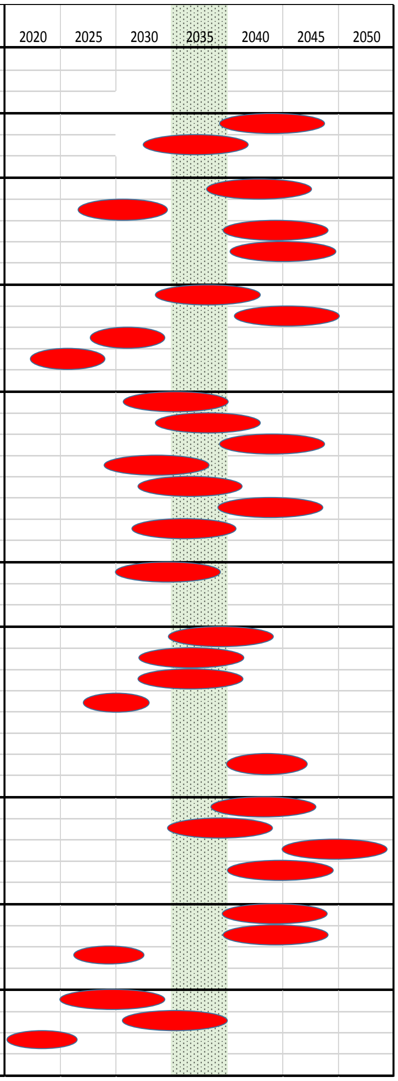
Fleet Life Expectancy

(Red Ovals Equal Range of End Service Dates)

Version: 2.0 dated 9 Jan 2018

Year given is the mid-point of the cell

Country	Platform	Numbers	Roles	In-Service	Notes
Belgium	NH-90	8	Transport + ASuW	2013	
	AW-109	24	Scout + Anti-Armour		
Canada	CH-149 Cormorant	14	SAR	2002	Extension till at least 2040
	CH-146 Griffon	85	Transport + SAR	1995	Replacement planned soon.
	CH-148 Cyclone	28	ASW	2015	
	CH-147F	15	Heavy Lift	2013	
Denmark	AW-101	13	Transport + SAR	2006	
	SH-60R	6	ASW + SAR	2017	
	AS-550C2	12	Light Utility	1990	
	Lynx Mk90B	6	ASW + SAR	1990s	Being replace with MH60R
France	AS-532 Cougar	23	Transport	1990s	
	EC-725 Caracel	20	Transport	2004	
	NH-90 Caiman	61	Transport + ASW	2013	
	SA-365 Dauphin	8	Maritime SAR	1990s	
	AS-565 Panther	15	Multi Maritime Ops	1998	Upgrade in 2009
	Tiger HAD	67	Attack	2005	Upgrade in 2025
	Helicopter Light Project	100-150c	Medium weight class		Replace several helo types
Iceland	AS-332L Super Puma	3	SAR	2005	
Italy	NH-90	104	Multi Role	2008	
	AW-101	34	SAR + CSAR	2001	
	AW-139	17	SAR	2012	Leasing contract.
	AW-129 Mangusta	59	Attack	1990	Replacement planned for 2025
	AB-206	32	Utility	1990s	Replaced by NH-90
	AB-205 + 212 + 412	58	Utility	1990s	Replaced by NH-90
	CH-47	24	Heavy Lift	1970-1980	
Netherlands	NH-90	20	Utility + SAR + Maritime	2010	
	AS-532 Cougar	8	Transport/CSAR	1990s	Upgrade done 2009
	CH-47D/F Chinook	11	Heavy Lift	Mid 1990s	14 CH-47 on order ISD 2020
	AH-64D Apache	28	Attack	1998	Plans to upgrade to AH-64E
Norway	NH-90	14	SAR + ASW	2016	
	AW-101	10	SAR + Utility	2016	
	Bell 412	18	Utility	1987	Extension planned till 2024c
Portugal	Lynx MK95	5	Anti Piracy	1990	Upgraded in 2010
	AW-101	12	SAR	2004	
	Alouette III	8	SAR/Training	1960s	



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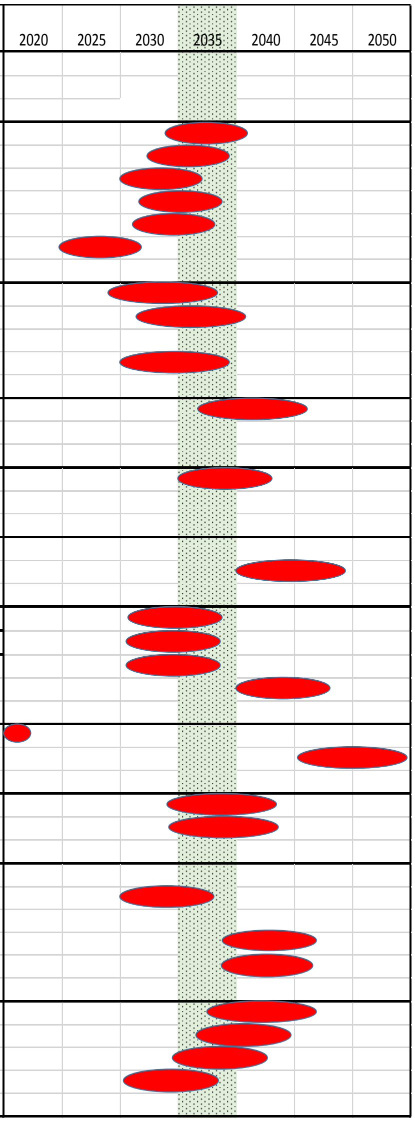
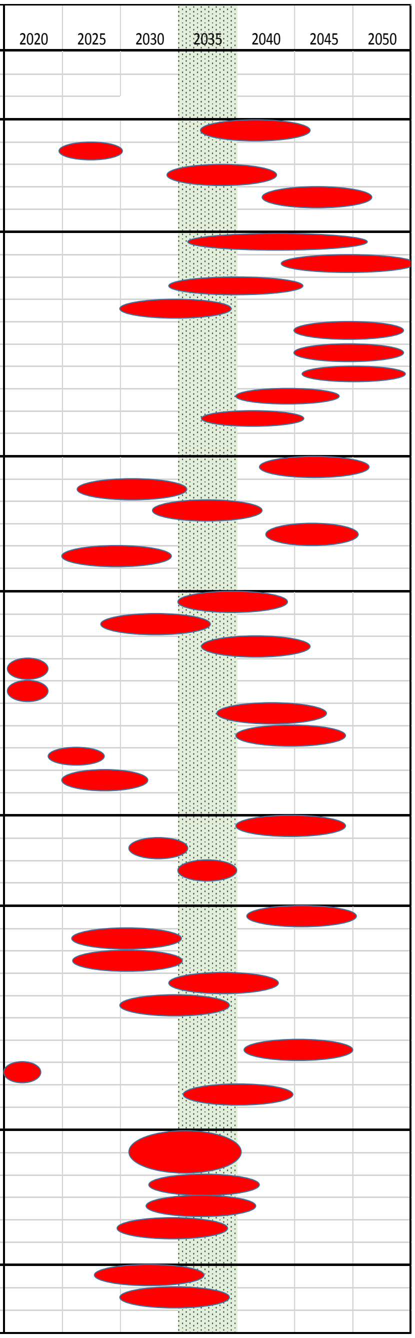
Country	Platform	Numbers	Roles	In-Service	Notes
Poland	PZL W-3	25	Utility + SAR	1993	Collaberation with Ukraine
	Mi-17	12	Utility + SAR	1973	Collaberation with Ukraine
	Mi-2	38	Utility	1973	Collaberation with Ukraine
	Mi-14	9	ASW + SAR	?	
	SH-2G	4	SAR	?	
	Mil-24	30	Attack	1990s	Replacement being discussed
Bulgaria	Mil-17	4	Utility	1985	Repair and modernisation
	Bell 206	2	Utility	1989	Repair and modernisation
	AS-565	3	Utility + SAR		
	Mil-24				
Estonia	AW-139	3	Utility + SAR	2008	
Latvia	Mi-17	4	Utility	1999	
Lithuania	Mi-17	3	SAR		
	AS-365	3	SAR	2016	
Romania	AS-330	35	Transport	1975	Upgrade to H215M
	AS-330L	22	Attack	2001	Upgrade to H215M
	AS-330L	3	Navy multi mission	2009	Upgrade to H215M?
	Attack Helicopter	45?	Attack	2019-2020	AH-1Z-Viper?
Slovakia	Mi-17M	13		1980s	Being replaced with UH-60M
	UH-60M	9		2017-2019	
Slovenia	AS-532	4		2004	
	Bell 412	8	Utility	?	
Albania	AS-350	3		1991	Operated by Min of Interior
	Bo-105	12			
	EC-145	1		2015	
	AB-206	7			
	AB-205	7			
Croatia	OH-58D	16		2016	
	Mi-171 SH	14			Overhauled 2004+2014
	Mi-8	14			Upgrade 2007
	Bell 206B	8	Trainer		



Version: 2.0 dated 9 Jan 2018					Year given is the mid-point of the cell
Country	Platform	Numbers	Roles	In-Service	Notes
UK	AW-101 Merlin	60	ASW + TTH	2001	MRCI + MOAC
	AS-330 Puma	34	Transport	1990s	MRCI + MOAC (Extend till 2025?)
	AW-159 Wildcat	58	ASuW + RECCE	2014	MRCI + MOAC
	CH-47	60	Heavy Lift	2018	Upgrade Fleets to F model
US					JMR
	UH-60 (various models)	2000c	Troop/CSAR/Utility	1979	Expected to be replaced by 2070
	MH-60+SH60F+HH60H	460	ASW + Multi Mission	1984	
	AH-1W/Z Cobra	200	Attack	1967	
	AH-64D	790	Attack	1984	Upgrade to AH-64E
	CH-43 Sea Stallion	500	Heavy Lift	1966	Replaced with CH-43K
	CH-47	510	Heavy Lift	1962	
	CV-22B Osprey	46	V/STOL	2007	Used by US Airforce
	MV-22B Osprey	253	V/STOL	2002	Used by the USMC
Greece	NH-90	20	Transport	2016	
	S-70	10	ASW	1995	
	AH-64 Apache	25	Attack	1995	Contract signed for 12x64D in 2003
	CH-47D Chinook	30	Heavy Lift	2018	
	AB-205 + UH-1H	87	Utility Light Med Lift	1990s	Replacment planned
Turkey	S-70B	57	Maritime + ASW	2010	T-70 Varient used
	UH-60	80	Transport		Links to Turkish Utility Helo Prog
	AS-532	20	Utility	?	
	UH-1	63	Utility	?	Being replaced with T-70
	AB-212	12	ASW	?	Being replaced with T-70
	CH-47 Chinook	6	Heavy Lift	1990s	
	T129-ATAK	27	Attack	2014	
	Mil-17	17	Transport	?	Replaced by UH-60?
	AB-206	26	Utility/Training	?	
Germany	NH-90	82	Multi-role	2009	ASW varient entered service 2017
	CH-53G	81	Heavy Lift	1973	Upgraded 2001
	EC-135	14	Training + Light utility	1995	
Spain	NH-90	22	Transport	2014	
	AS-332B - Super Puma	15	Transport	?	Upgrade to H215.
	AS-532UL - Cougar	14	Transport	?	
	SH-60F	14	ASW	2010	
	Bell 212	7	Utility	1974	Upgraded 2017
	Bell UH-1H	14	Utility	?	Being phased out?
	CH-47	17	Heavy Lift	1990s	
	BO-105	14	Attack, anti-tank	1980s	Being replaced with Tigre
	Tigre	24	Attack	2007	
Czech Rep	Mil-8	3	Utility	1984	Replaced with 12 UH-1Y/AW139W
	Mil-17	5	Utility	1984	
	Mil-171 SH	15	Utility	2004	
	PZL W-3	10	Utility	1995	
	Mil-24V	10	Attack	1976?	Replacement planned: AW139M?
Hungary	Mil-17	13	Utility	?	Overhauled in 2016
	Mil-24	12	Attack + Transport	?	Overhauled in 2018



Appendix C

STO AVT-005 Report[9], Executive Summary

This report has been produced by a team established by the NATO Science & Technology Organization (STO) to provide rotorcraft technology input to the NATO Joint Capabilities Group Vertical Lift (JCG-VL) Team of Experts (TOE) for a Next Generation Rotorcraft Capability (NGRC). A previous activity relating to Future Rotorcraft Requirements identified common rotorcraft needs, replacement timeframes and opportunities for the NATO rotorcraft fleet, this is reported separately.

The importance of helicopters in past and current military operations is widely recognised; in addition the current state of technology is such that significantly enhanced capability is now achievable.

This report provides an overview of technical areas considered to be key drivers for future rotorcraft design. For each of these areas, an assessment of the operational benefits, enabling technologies (including a view of their current readiness level and likely attainment of Technical Readiness Level (TRL) 6), their impact on other areas, the key players and links to other NATO activities was undertaken. The technical areas considered were, in no particular priority order:

- Active Flight Control Systems
- Advanced Avionic Architectures
- Increased Performance
- Human Factors
- Survivability
- Materials and Manufacturing
- Cost of Ownership Reduction

Conclusions and recommendations for each technical areas are presented, a number of wider conclusions are:

- Defense budgets are likely to remain constrained leading to the use of monitoring technologies that will lead to a reduction in cost of ownership.
- Future rotorcraft will be required to transport similar payloads to today’s vehicles over longer unrefueled ranges at greater speed and in “hot and high” conditions without sacrificing agility.
- It is expected that future rotorcraft will become increasingly modular, adopting an open architecture approach across all installed systems (including on board aircraft systems, mission systems and Defensive Aids Systems (DAS). Modularity will not be confined to avionics but will encompass structural elements and mission packages allowing common airframes to support a wide range of missions.

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[9] NATO Science and Technology Organization (STO), Applied Vehicle Technology (AVT) Study 005.

- The operational environment is likely to become increasingly hostile with adversaries deploying complex threat weapons, often in asymmetric situations. Enhancing platform survivability is considered a high priority and in particular the ability to react to evolution of the encountered threat rapidly.
- Human Factors Integration will become more significant as higher levels of automation are adopted for reducing crew workload. The possibility of operating future helicopters with or without aircrew will also be a consideration, as will the ability to team between manned and un-manned platforms.
- There is likely to be increased use of virtual integration & model verification during the design cycle of a new vehicle.

Appendix D

NIAG SG-219 Executive Summary

NIAG Study Group (SG) 219 leveraged industrial expertise from across NATO to recommend disruptive capabilities for Next Generation Rotorcraft (NGR) and identify enabling technologies. These recommendations, developed to exploit rapidly evolving technology in the context of global trends and aerospace industry-wide initiatives, identify technologies and approaches to enhance operational capability throughout enduring campaigns, minimize maintenance and manpower and other through-life costs, and enable responsive upgrades. The SG-219 output will assist the NATO JCGVL Team of Experts (TOE) in developing a NATO Staff Requirement for a future vertical lift platform. The output will also inform and stimulate national interest and timely investments in key science, technology and research supporting any NGR development program which would enter military service around 2035.

SG-219 identified capabilities applicable to all classes of rotorcraft systems, and across the range of NATO missions in ATP-49G and maritime roles. Teams were formed to explore the platform, mission systems, human-machine interface (HMI), survivability, operations, teaming, manufacturing, support and force structure. These teams identified the CAPABILITIES important to military rotorcraft effectiveness and costs within their assigned domain, METRICS to characterize current and future capability, and TECHNOLOGIES to achieve step changes in capabilities and costs.

SG-219 considered the many significant global trends and aerospace industry-wide initiatives that are obliging aviation regulators, principally FAA and EASA, to understand and approve new technologies and capabilities. These include:

- UAS Certification initiatives
- Commercial on-demand vertical flight
- Uniform / international regulatory standards (e.g. performance-based navigation, PBN) and Multi-national certification and maintenance approvals.
- Loss of national military waivers increasing need to meet civil certification and/or operational requirements
- Leveraging commercial off-the-shelf (COTS) technologies and components
- Non-deterministic control methods for automation and autonomy

SG-219 identified a wide variety of emerging and promising technologies, and characterized their impacts on capabilities, but did not address military effectiveness. The list of technologies identified is assessed as not exhaustive, but comprehensive.

Three bold and innovative system-level approaches were identified that can dramatically increase flexibility in acquisition and operation, increase effectiveness, improve availability, facilitate new support concepts, reduce through life costs and accelerate future progress:

- **Modularity:** NGR will be 'Born Modular', to enable agile, scalable and affordable acquisition and sustainment within NATO and across appropriate non-NATO nations. The NGR backbone will be designed and fitted for modules but not fitted with each module, and capable of supporting the range of required missions and applications.
- **Multiple Level Capability:** Multiple qualified modules, like familiar personal computer 'peripherals', will be available at the outset for each key function, nominally in three (3) levels here termed Austere, Standard and Enhanced. The "Standard" level will be capable of undertaking, with appropriate modular upgrades, most challenging mission sets in most environments, whilst the "Austere" capability will permit cheaper acquisition and operating costs in more benign environments, potentially bringing the cost-point of the basic airframe to a more widely affordable level. The "Enhanced" level[10] will be capable of delivering all mission sets in all environments at an acceptable military risk – its modularity conferring the ability to respond rapidly to counter dynamically evolving high-end operating threats.
- **Condition Based Operation (CBO)** Dynamic planning and employment decisions will be made in real-time based upon current, complete and trusted cognizance of system and component configuration, capability, status and conditions.

Together these capabilities will blur/combine/align acquisition and support approaches.

Leveraging smart platform integrated modular architectures for avionics, mission systems, propulsion, electrical power, and structures will represent a step change in capability planning. Future systems with smart instrumented peripherals with full usage history, and real-time self-awareness through diagnostics and prognostics will be rapidly reconfigurable in real-time at the operational level. This knowledge with proactive analysis of courses of action will enable robust scalable capability and effects based on current status, rendering the published Operator Manual all but obsolete. Applying these features at the system level on a broad scale at the outset represents a paradigm shift in approach, with technical, regulatory and industrial base implications. The approach will enable dramatic operational, acquisition and sustainment flexibility with significant Through-Life Cost savings. Subsequent procurements using 'rolling/spiral upgrades' will make the present-day '20-year replacement acquisition' cycle obsolete.

All technologies that SG-219 identified to enable the proposed NGR capabilities are presented in Chapter 7 of this Report. Many of the capabilities and the associated technologies identified here offer advantages outside the NGR platform and should be considered holistically with broader NATO implications.

SG-219 derived several significant conclusions and recommends associated investment in specific research. These Conclusions and Recommendations are found in Chapter 8. It is urgent to embark on the essential enablers for the innovative NGR approaches, including well documented interfaces and standards across all stakeholders, and to recognize that significant cultural changes in requirements, acquisition, business models, and regulatory

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[10] Analogous to a Special Forces / Special Operations Command (SF/SOCOM) Tier 1 Asset

approval will be necessary. The most significant and urgent recommendations to establish capability, technology or regulation for IOC in 2035 are:

- Develop and deploy hardware and software interface standards enabling NGR mission systems, structures and propulsion to be “born-modular”
- Examine 100% Condition-Based Operations, to evaluate value and assess feasibility
- Regulatory and Airworthiness authorities (military and civil, FAA/EASA) to facilitate understanding and acceptance of modularity and rapid re-configurability to achieve common standards.
- NATO leverage regulatory culture changes and embark on positively influencing them.
- Explore Direct Energy Weapons, as both a capability (offensive/defensive) and a threat.
- Explore hybrid propulsion for reduced emissions/signatures and high-power payloads.
- Accelerate development of standardized, cyber-secure open modular architectures
- Perform operational analysis to identify the relative values of new proposed capabilities.
- Leverage the potential of MUM-T, with corresponding UAS certification (including use in non-segregated airspace).
- NATO needs to be aware of the requirements for future Precision Based Navigation (PBN) airspace regulations to operate in peacetime – reliance on waivers will be unsustainable.
- Prepare for the denial of space-based precision navigation and time capabilities during conflict.

Appendix E

Draft Generic NATO Staff Requirement for a Next Generation Rotorcraft

(Provided as a separate NATO-only document)