Command and Control in a Fifth Generation Air Force: Coordination Requirements of Air Operations with F-35 and the Command and Control-System of the Norwegian Armed Forces

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PRACTICE-ORIENTED ARTICLE

HANNA MARIE BJERKE

SIGMUND VALAKER

**Author affiliations can be found in the back matter of this article*

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ABSTRACT

This article discusses the ways in which the F-35 Lightning aircraft might affect the command and control (C2) of the Royal Norwegian Air Force. It emphasises the importance of coordination answering questions regarding the effect of the implementation of the F-35 on interdependencies with other capabilities. This foundation is further used to discuss possible implications for elements central to C2 such as procedures, personnel, and communication and information systems. Based on the capabilities of the F-35 system, we find a development of interdependencies across domains and C2 levels in the Norwegian armed forces; the complexity of these interdependencies, influenced both by the execution of air operations and by environmental contingencies, means that the organisation needs to be flexible in its use of coordination mechanisms. We find that interdependence, and the coordination necessary if it is to be successful, have implications for command and control of air operations involving F-35 aircraft. We suggest the organisation should adopt a more active use of both hierarchical and horizontal structures to accommodate the sharing of knowledge and information across domains and C2 levels. Procedures need to include methods and systems for the delegation of authority, and personnel require knowledge of interdependencies and multi-domain operations. Finally, communication and information systems need to be available, interoperable, and robust.

CORRESPONDING AUTHOR:

Hanna Marie Bjerke

Royal Norwegian Air Force, NO

hbjerke@mil.no

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INTRODUCTION

The increasingly dynamic and complex nature of the contemporary security environment precipitates a need for flexible military forces with credible and relevant capabilities (Etterretningstjenesten, 2020; Kainikara, 2015). The fifth-generation air force – airpower characterised by a flexible use of military force and rapid information-exchange serving to maintain situational awareness in support of efficient command and control (C2) – was developed to efficiently counter threats in this dynamic environment (Kainikara, 2015; Laird, 2009; Layton, 2017).

An organisation's decision to introduce new technology frequently leads to change (Lawrence & Lorsch, 1986) – and the Norwegian Armed Forces' decision in 2008 to acquire the F-35 (Forsvarsdepartementet, 2008), an air system designed for the dynamics specific to the present era (Layton, 2017), signified the adoption of an altogether new generation of airpower. The F-35 offers vast possibilities in the execution of airpower (Laird, 2009; Lockheed Martin, 2017; Tørrisplass, 2018); some even refer to the F-35 as a revolution in airpower in general (Kainikara, 2015).

For the Royal Norwegian Air Force (RNoAF), two aspects of the aircraft's potential are particularly interesting: its capacity to execute a larger suite of different air roles, and its ability to execute airpower both alone and in concert with actors from multiple domains (Forsvaret, 2018b). This give the possibility of more efficient military operations where coordination between the F-35 and interdependent assets, such as supporting air assets, naval and land assets, will be crucial to be able to achieve the common goals desired.

There is a concern, both nationally and internationally, with the C2 structure's capacity to integrate and optimise the use of complex fifth generation air systems (Forsvaret, 2018b; Alberts & Hayes, 2003). C2 is a matter of both *focus* in decision-making and *convergence* in the coordination of resources and people for the achievement of a common goal (van Creveld, 1985; Forsvaret, 2018a; Alberts & Hayes, 2006; Alberts, 2007). Obliged to guarantee the means of coordination between F-35 and other assets, in ways both flexible and appropriate to the situation, C2 is thus critical to the success of the RNoAF's turn to the fifth generation air force (Forsvaret, 2018b). Lack of coordination between interdependent actors can cause mission failure (Thompson, 1967).

In this context, inquiry into the effect on national C2 of the implementation of F-35 in the RNoAF[1] – specifically, the system's integration with other capabilities – covers much ground. But, we believe, ongoing and informed debate on this issue is vital. This article is an attempt to delineate some potential roads ahead for one specific area of implementation of the F-35: coordination. Other aspects (technological developments, the purposes for which the F-35 will be used, allied and hostile operations, for example) will surely also impact C2.

In what follows, we begin by setting out the theoretical framework this paper employs: interdependence and coordination theory, and contingency theory. We use this theoretical approach because, as Thompson (1967) has set out, interdependencies between actors necessitate degrees of *coordination* – a key element in C2 (van Creveld, 1985; Alberts & Hayes, 2006). We continue by addressing national C2, differentiated into the elements of organisational command structure, processes, and communication and information systems (CIS), of which the latter enables the execution of C2 itself (Forsvaret, 2018a). After this, we briefly define some key characteristics of the F-35 relevant to coordination and, in light of this, analyse both interdependence and coordination requirements in air operations with the F-35, and how these factors are influenced by environmental contingencies. We continue by elaborating on how these results influence the execution of C2 (structure, processes and CIS).

In the analysis, we also draw on research on multi-teams. This research provides a framework for the discussion of coordination among several subsystems particularly germane to the type of organisation that might employ the F-35 (Rico et al., 2018; Zaccaro et al., 2020). A multi-team system we may define as two or more tightly coupled interdependent teams (entities) in pursuit of a superordinate goal (Rico et al., 2018; Mathieu, Luciano & DeChurch, 2018).

1 The article is based on a Master's thesis completed with the Norwegian Defence University College in the fall of 2020.

The building block of multi-teams, the team, can be defined as "a bounded and stable set of individuals interdependent for a common purpose" (Wageman, Gardner & Mortensen, 2012). We may consider formations of F-35 aircraft cooperating with other entities to be a multi-team. Finally, the study concludes with recommendations regarding the further development of C2 in the RNoAF and in the Norwegian Armed Forces in general.

Focusing on coordination, we argue that the flexible use of coordination mechanisms is a prerequisite for the optimal usage of the F-35. Coordination can comprise *activities*, *understanding* and *interests* (Mathieu, Luciano & DeChurch, 2018). In the context of F-35 operations, "activities" can include the provision of kinetic effects that may be needed in a wider joint operation. The coordination of activities is a matter of when and where such effects should be used in an integrated way. "Understanding" relates to the apprehension of a situation and the exchange of, for example, sensor data between F-35s and relevant decision-makers The coordination of "interests," finally, is significant when the F-35 is a scarce resource in situations when decisions must be made regarding the deployment of the aircraft in a given, wider, context. We also find environmental contingencies highly relevant on account of the dynamic nature of air operations (Forsvaret, 2018) and the ways in which situational demands and internal factors can impact coordination (van der Ven, Delbecq & Koenig, 1976).

This article contributes to the theoretical understanding of the fifth generation air force. It builds on unclassified open-source documents (for a typical example, see Hoeben, 2017). In a Norwegian context, unclassified studies of the F-35 system are infrequent and mostly focused on strategic relevance (Tørrisplass, 2018) and the command aspect of C2 (Stensrud, Valaker & Mikkelsen, 2020). This study's particular importance and relevance lie in its specifically addressing coordination between the F-35 and other military entities. Implementation of the F-35 is ongoing, and the ultimate implications are unlikely to be fully understood at present. While a full survey of the factors affecting C2 is too broad for the scope of this article, as we have indicated, we believe it to cover important ground regarding coordination in C2 in the context of the fifth generation air force in coming years.

COORDINATION AND INTERDEPENDENCE

The term "interdependence" designates relations between work-processes, where changes in one element affect the condition of others; it will always exist in systems where different components must function together (Mintzberg, 1979; Scott & Davis, 2007). To integrate a collective set of interdependent tasks, the components need to interact in a process of coordination (Thompson, 1967; Scott & Davis, 2007). Coordination requirements are settled by the level of interdependence between specialised teams (van der Ven, Delbecq & Koenig, 1976; Okhuysen & Beckhy, 2009). Coordination is realised using different coordination mechanisms, defined as the organisational arrangements or methods allowing individuals to realise a collective performance (Mintzberg, 1979).

We will present three different levels of interdependence – *pooled*, *sequential* and *reciprocal* – as set out by Thompson in 1967, before reviewing formal and informal coordination mechanisms.[2] Finally, we describe how the levels of interdependence and different coordination mechanisms relate to each other.

The different levels of interdependence are based on the flow of work-related tasks and resources between individuals, teams and multi-teams in an organisation. These levels are illustrated in ***Figures 1, 2*** and ***3***, starting with processes characterised by individual work emerging into team-based processes.

In situations where members or teams can work individually, Thompson (1967) describes the interdependence as "pooled." In these situations, the different teams will have direct access to all necessary resources (i.e., information and tools), including decision-authority to complete any assigned process or task. To identify links between individual processes, all links within the organisation need to be observed as a single system; the quality of each individual process can only be measured when the final objective is accounted for.

2 For an overview of this distinction, see Brosius et al. (2017).

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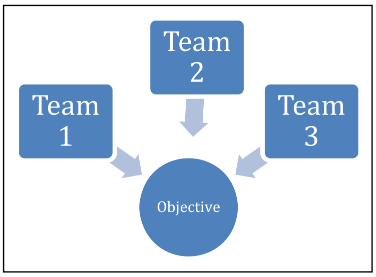

Figure 1 Pooled interdependence.

Sequential interdependence occurs when one team is dependent on inputs from another team to complete an assigned task. Every team can influence the objective once, and the sequence of the completion of tasks is no longer irrelevant. Thus, there will be consequences for the overall result if one team deviates from the pre-set order, or fails to deliver its input (Skipper et al., 2008).

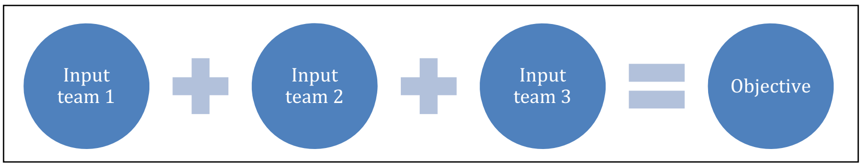

Figure 2 Sequential interdependence.

Reciprocal interdependence, the most complex type, manifests when tasks, resources and decisions flow back and forth in an organisation (Mintzberg, 1979). Saavedra, Early and van Dyne (1993) describe these situations as two-way transactions, where the order of different actions can be flexible, and actors can influence the overall result more than once.

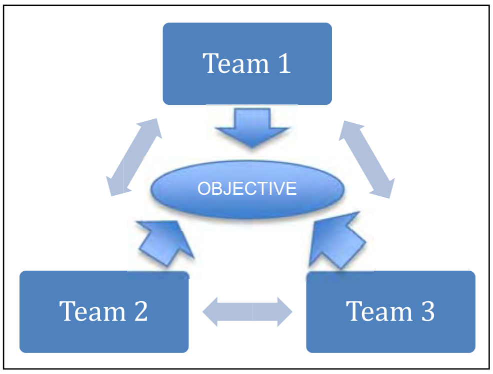

Figure 3 Reciprocal interdependence.

To handle interdependence, the organisation uses coordination mechanisms which can be categorised in multiple ways (Okhuysen & Bechky, 2009). Brosius et al. (2017) differentiate between *formal* and *informal* coordination, where formal coordination is described as part of the structural design, and informal coordination denotes direct interaction between individuals and teams (Mintzberg, 1979). Their purposes are also different: formal coordination aims to *reduce* the need for coordination, and informal coordination aims to *handle* the coordination-need (Srikanth & Puranam, 2011).

Formal coordination mechanisms include both *forms* and *methods*. We can understand an organisation's structural form, or design, to denote the formal arrangements determining how tasks are accomplished and how decision-authority is delegated inside that organisation (Mintzberg, 1979). Complex organisations are commonly structured hierarchically, where higher levels handle coordination aspects beyond the scope of the lower levels (Scott & Davis, 2007). Structural design also includes lateral arrangements. Combined, they allow vertical and horizontal coordination within the organisation. Depending on the delegation of authority, an organisation can be centralised (vertically), decentralised (horizontally) or exist in other hybrid forms (Mathieu, Luciano & DeChurch, 2018), and can use horizontal arrangements like liaisons or core groups from different units to reduce coordination requirements (Rico et al., 2018). This use of vertical and horizontal coordination forms serves to make the manner in which processes are performed predictably to the organisation's members (Okhuysen & Bechky, 2009).

In addition to these structural arrangements, formal methods include the use of standardisation and plans. Standardisation serves to ensure a set process for the completion of a specified task or activity, again contributing to predictability within the organisation (Mintzberg, 1979). In air operations, we see the well-known example of Zulu time. Training, education, reporting and terminology can all be standardised (Okhuysen & Bechky, 2009).

Standardisation, however, limits an organisation's capacity to process new information, posing challenges in environments where changes are difficult to predict. For this reason, it has been assessed as most efficient for coordination in stable environments (Thompson, 1967; Scott & Davis, 2007). In more dynamic situations, it is more appropriate to employ plans and schedules in assisting individual members in their efforts to coordinate action in time and space. More specifically, a plan creates links between available resources and necessary actions, so reducing complexity in the situation at hand (Okhuysen & Bechky, 2009). Used in combination, the two methods complement each other, ensuring the efficient use of resources to fulfil the organisation's objective (Okhuysen & Bechky, 2009).

In specifically dynamic situations, informal coordination mechanisms can be more efficient still (van der Ven, Delbecq & Koenig, 1976). Espinosa, Lerch and Kraut (2002) present two methods: *explicit* coordination, through direct communication, and *implicit* coordination, through the adjustment of behaviour based on the evolving situation (Mintzberg, 1979; Srikanth & Puranam, 2011).

Explicit coordination coordinates processes, individuals and teams both horizontally and vertically, either through individual conversations or larger gatherings or meetings (van der Ven, Delbecq & Koenig, 1976). Implicit coordination requires more knowledge, both on an individual and systemic level, being based on the involved actors' predictions of how the situation will evolve. Efficient use will thus require a general situational awareness based on a commander's intention for the specific mission or task – which again requires extensive knowledge of the assigned task, including the behavioural patterns of cooperating actors (Mintzberg, 1979; Rico et al., 2018; Espinosa, Lerch & Kraut, 2002). Informal coordination is thus more costly to use than formal methods of coordination, as the necessary level of knowledge needs to evolve over time (Mintzberg, 1979).

Research suggests that the degree of interdependence among entities could influence what is the most appropriate coordination mechanism. This relation is summarised in ***Table 1***. The achievement of efficient coordination relates closely to stability in the environment: the need to process new information will vary commensurately with the complexity of the environment. Note, also, the relevance of what is known as the Guttman scale[3] – higher levels of interdependence also incorporate lower levels (Thompson, 1967).

As shown in the table, situations with stable environments and low levels of uncertainty are related to pooled interdependence. This is handled most effectively by rules and standardisation. This coordination method will ensure a common process for the completion of a task where inputs from others are less relevant for the overall result (Thompson, 1967). When the complexity of the situation increases, interdependence between teams may increase with it, and plans will be more effective because of its ability to link actors with the resources required (Thompson, 1967).

Finally, in the most complex situations, teams need to interact closely to ensure a shared situational awareness. Again, according to the framework set out by Thompson in 1967, this is most efficiently coordinated through informal coordination mechanisms. This does not, however, exclude the use of formal methods, which will complement explicit and implicit coordination in the course of an ongoing situation.

INTERDEPENDENCE	MECHANISM OF COORDINATION
Pooled	Formal standardisation
Sequential	Formal plans (and standardisation)
Reciprocal	Informal direct communication (explicit) and mutual adjustment (implicit); formal methods

Table 1 Interdependence and Related Coordination Mechanism.

3 Guttman-scale is a cumulative scale where elements are ordered in hierarchical manner, building on the lower level's characteristics. Meaning - what is true for pooled interdependence will be true for reciprocal interdependence (Thompson, 1967).

Similar evaluations could be made for the coordination form or how responsibility for coordination is delegated. Classic theories assume that complex situations lead to an increase in the use of horizontal arrangements and thus can affect interdependence between involved actors (van der Ven, Delbecq & Koenig, 1976). Horizontal coordination could be particularly important where there are high levels of interdependence, specifically if using implicit coordination (Rico et al., 2018). This could reduce both the cost of communicating across many hierarchical levels and the need for direct communication between horizontal entities. On the other hand, coordinating laterally could become a too heavy cost in terms of communication and confusion given the twin absences of a centralised direction and the development of a shared understanding (Lanaj et al., 2013). This can be significant when major changes to the multi-team system are called for (Rico et al., 2018).

This indicate that there is no best way of coordinating but rather that it is situation dependent and can be influenced by the use of hierarchy and delegation of decision-authority (Rico et al., 2018; Zaccaro et al., 2020). This supposition is further supported by theory on environmntal contingencies, as we will now see.

ENVIRONMENTAL CONTINGENCIES

An organisation will both affect and be affected by changes in its environment. The ways in which that organisation manages the adaption required of it can confer on it advantages such as increased internal efficiency and legitimacy in the society of which it is a part (Mintzberg, 1979).

While environmental contingencies can be understood in several ways, uncertainty and ambiguity regarding the task environment are certainly important (Scott & Davis, 2007). Uncertainty can be divided into *complexity* (number of elements and number of relations among elements in an environment) or *dynamics* (the rate of change in elements in the environment; for a summary see Valaker et al., 2020; Grote, Kolbe & Waller, 2018; Luciano, Nahrgang & Shropshire, 2020). In a military context, these concepts can be used to characterise enemy threats, as these can be apprehended both numerically (the number of missiles, for example) and as in interrelations (the connection between enemy missiles and the C2 system directing them to their correct targets). The rate of change (the frequency of missile launches, say, or changes in their trajectory) can exacerbate threat, while in a wider political setting the threat can be highly ambiguous – an opponent's true intentions, for example, may be highly difficult to parse.

According to Lawrence and Lorsch (1986), complexity and the rate of change in the environment can be mitigated through differentiation and the delegation of authority. For them, horizontal differentiation (that is, the organisation of different teams based on time-perspective) is efficient in handling dynamic environments – a claim supported by coordination theory. The rate of change can be handled by delegating authority to teams close to the situation, which will increase the need for both coordination and horizontal connections (Lawrence & Lorsch, 1986). This is to say that active use of organisational design and the delegation of authority can influence interdependence and thus coordination needs (Lawrence & Lorsch, 1986; Rico et al., 2018).

Summarised, both internal interdependencies and environmental contingencies provide perspective and context necessary to the understanding of principles and structures in air C2 and F-35 capabilities related to coordination.

COMMAND AND CONTROL IN AIR OPERATIONS

In this section, we will further describe air C2 as comprising the elements of procedure, structure (personnel), and CIS. We use the four-phase OODA ("Observe, Orient, Decide and Act") decision loop described by John Boyd[4] to illustrate C2, before presenting the C2 principle of centralised command and decentralised execution – the manner in which air C2 is commonly executed. After this, we present the Norwegian command structure as it is currently formalised, before briefly commenting on CIS.

4 See Osinga (2007) for details on John Boyd's theoretical contribution.

Fifth generation platforms like F-35 are designed to connect actors across decision levels and domains (Kainikara, 2015). The efficient use of these systems begins with the function of C2 (Forsvaret, 2018b, Forsvaret, 2019). C2 can be described as the tool military forces use to address uncertainty when facing complex environments (Alberts & Hayes, 2006). It is executed through the transformation of information into actions with the purpose of obtaining specific objectives (Luftforsvaret, 2018).

To describe this process, we will use John Boyd's OODA decision loop (Osigna, 2007). This loop, illustrated in ***Figure 4***, is subject to the influence of both internal and external environments. Different and mutually reactive OODA loops can thus be executed in the command structure (Hoeben, 2017), meaning that the process of decision-making must be executed in a continuous and iterative fashion at all command levels.

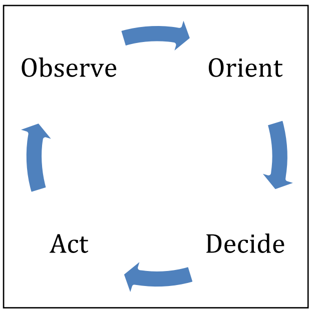

Figure 4 OODA-loop.

In the observation phase, the intention is to gather information from the environment of interest relevant to an emerging situation, such as changes in normal patterns of activity – increases or decreases in air activity, for example. Relevant information can alter with the level the observer is linked to; different command levels will also observe processes on lower and higher levels for indications relevant to their specific mission.

Based on available information, decision-makers will orient themselves so they may arrive at an overview of circumstances that can influence the mission. This can include political guidance, the legal framework, ongoing operations or available forces. Commander's intent will be specifically important if the different levels are to successfully focus the organisation and missions on a common objective.

In phases one and two, the command structure develops situational awareness. This is the foundation of sound decisions. Based on available information, the decisions can materialise as specific missions, organisation of planning groups, or continued observations. Finally, all decisions will be given as orders to dedicated forces who will act to achieve the task they have been given (Osinga, 2007).

As we have seen, the core of a fifth generation air force is flexibility and decision-speed (Kainikara, 2015). Air C2 ensures decision-speed through the principle of centralised command and decentralised (or situationally dependent) execution (Forsvaret, 2018a). This C2 principle is a variation of mission command[5] with some limitations to operational freedom on executive levels. A more centralised control of airpower arrives from the need to ensure joint prioritisation of a limited resource, balanced towards the tactical flexibility needed to handle a complex and dynamic environment (Forsvaret, 2018a).

To ensure situationally dependent execution, air forces use a system of Tactical Battle Management Functions (TBMF). TBMFs are different functions, including identification, interception or engagement of targets, where the authority to execute can be delegated to actors in the command structure. Decision-authority is regulated by procedures often controlled in time and space giving actors in the command structure the possibility to delegate or to retain authority based on the current situation (Forsvaret, 2018a). In essence, this exemplifies ways of standardising the execution of missions, rules and ways of delegating the responsibilities for coordination.

These responsibilities are held in the command structure, shared equally among NATO members and separated into strategic, operational and tactical command levels. There is

5 Mission Command is the foundation of C2. It highlights the commander's intent and the executive level's freedom to act in accordance with this intent – *what* to do, that is, not *how* it should be done (Forsvaret, 2018).

also the executive level, in Norway organised into different Air Wings. The command levels have different roles and functions based on which process, or part of a process, they lead. The national strategic level, integrating political leadership from the Department of Defence (DoD) and military strategic leadership from the Armed Forces Staff (FST), sets the framework for the use of Norwegian military force. This framework acts at the operational level in the National Joint Headquarters (NJHQ). This is the level that translates political guidance into military objectives, further disseminated to the tactical level (Forsvaret, 2019). In the RNoAF, the National Air Operations Centre (NAOC) will detail these objectives into Air Operations Directives and Air Tasking Orders which provide the final detailed tasking to each Air Wing at the executive level. At this level, we find the air squadrons, including a Control and Reporting Centre (CRC). The CRC produces a recognised air picture, contributing to situational awareness and assuring the battle management of allocated air assets (Forsvaret, 2018a).

This geographically separated command structure is tied together through the use of CIS, guaranteeing the exchange of information and the ability to communicate vertically and horizontally in the organisation. This is done through several systems on different levels of classification, which enable communication through voice or data (Forsvaret, 2018a). While we will not elaborate on technical details, we will return later to the ways in which these C2 elements can be influenced by the introduction of F-35.

F-35 AND A FIFTH GENERATION AIR FORCE

A fifth generation air force largely exists as a response to a more dynamic and complex threat-environment making new demands of concepts for air operations and an air system's capabilities. The RNoAF describes the present environment as an important deciding factor in the choice of a new fighter. It is important, indeed, to note Norway's geopolitical environment, in which the ability to deter and overcome situations of anti-access and area denial (A2AD) can be crucial in securing operational freedom of movement (Forsvarsdepartementet, 2008; Forsvaret, 2018b). We will here focus on the potential the F-35 affords the RNoAF in the execution of different airpower roles and the method of executing airpower itself.

The F-35 Lightning is a single-seat multi-role fighter jet manufactured by the American company Lockheed Martin (Lockheed Martin, 2017). This fifth generation air system is particularly remarkable for its combination of advanced sensors and systems and for how the information it makes available can be amalgamated to provide the pilot with a superior situational awareness (Laird, 2009; Layton, 2017; Lockheed Martin, 2017). The design of the fighter means it is more difficult to detect in high-threat areas resembling the A2AD-conditions particularly relevant to the Norwegian context (Forsvaret, 2018b).

These advanced sensors and systems can potentially increase the range of airpower roles to which a fighter can contribute in a Norwegian operational milieu. The RNoAF claims that integrating the F-35 will lead to a more efficient execution of roles like counter-air, air interdict (AI) and close air support (CAS), in addition to a quantitative increase with the roles of Intelligence, Surveillance and Reconnaissance (ISR) and Anti-Surface Warfare ASuW (see Forsvaret, 2018b). The F-35 can also contribute to strategic attack, which, while not new to the mission portfolio of the fighter aircraft, can now be executed with a decreased level of risk when compared to a fourth generation fighter such as the F-16 (Forsvaret, 2018b).

In addition, the advanced functions of the F-35's radar allow it to contribute to electronic warfare (EW), the active and passive use of the electronic spectrum (Forsvaret, 2018a). By providing EW data to intelligence-development and to ongoing OODA loops, the aircraft also can contribute to C2 processes (Hoeben, 2017). The F-35 can thus contribute to the domains of information and cyber in addition to the more traditional air, land and maritime domains. Together this offers the potential to increase the flexibility and impact of airpower (Forsvaret, 2018b). It can further affect the political climate by serving as a more effective national deterrent (Tørrisplass, 2018).

Operational concepts of the ways in which the F-35 can be used also provide flexibility and increased effectiveness. A key to our understanding of fifth generation airpower is operations executed in a network (Layton, 2017) – a system of interdependent teams of specialists, each with their own goals sharing superordinate goals (Rico et al., 2018). Together, these teams address complex and often time-critical events (Lanaj et al., 2013). The purpose of a network is to execute efficient operations where the ability to maintain a continuous flow of information in support of common situational awareness is vital (Layton, 2017). In these cases, coordination is a principle criterion for success (Rico et al., 2018).

The members of this network perform the roles of *decision-maker* (limited by the delegated decision-authority), *sensor* (gathering information) and *shooter* or *effector* (launching kinetic or non-kinetic weapons), depicted in ***Figure 5***.

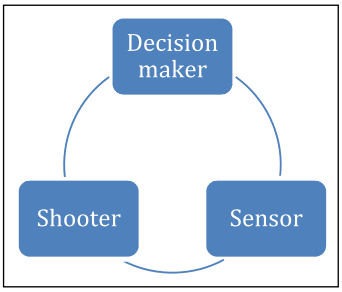

Figure 5 Decision-maker – sensor – shooter.

These different roles will be allocated dependent on the actor's capability (Lanaj et al., 2013) and the F-35 system here proves its flexibility by being able to execute all roles as applicable (Kainikara, 2015; Layton, 2017). Consequently, the F-35 can connect different command levels and domains operating within a network but can also use its capabilities in autonomous operations. These missions are described by NATO (2018) as missions where the authority for independent execution, including the right to choose targets and weapons, is delegated to flight-lead. This authority is linked to a specified level of Collateral Damage Estimation (CDE, an assessment of the likelihood of unintended damage) and rules of engagement to which the flight-lead is bound, restricting possible targets (NATO, 2016).

To summarise, F-35 is a flexible air system, both as an autonomous asset and as a node or nodes in a network. A team of F-35s can contribute with information, decisions and effects in a fifth generation air force where the ability to support multiple domains can strengthen each individual domain. It can also confer joint effects in a multi-domain environment.

As coordination is crucial in avoiding mission failure (Thompson, 1967), we will now turn to the coordination-needs created by the F-35 system.

INTERDEPENDENCE AND ENVIRONMENTAL CONTINGENCIES IN AIR OPERATIONS WITH F-35

The analysis of interdependence is contextualised through a framework consisting of an activity (AI, ASuW, CAS and strategic attack), a method of operation (autonomous or network/netted) and a level of authority (decentralised or centralised). We understand a centralised network to be a network in which decision-authority is held at the tactical command level or higher; in a decentralised network, decision-authority can be delegated to a platform, be it F-35, frigate or CRC, based on the system of TBMFs (Forsvaret, 2018a).

The airpower roles or activities are chosen to illustrate F-35's capacity to support multiple domains. They also offer the possibility of analysing the influence of the delegation of authority on interdependence, since these missions must include all network roles (decision-maker, sensor and shooter). Below, we comment briefly on implications of the F-35's ISR capabilities and refer to Hoeben (2017) for a more detailed elaboration of ISR and C2. Further, we analyse how interdependence develops between F-35 and actors from strategic (DoD/FST), operational (NJHQ) and tactical (NAOC) command levels, and review interdependence between the F-35 system and actors on the executive level – the CRC, maritime patrol aircraft P-8, frigates from the maritime domain, Joint Terminal Attack Controller (JTAC), which can support targeting in the land domain, and Ground Based Air Defence (GBAD), which defends and protects areas or objects from air threats (Forsvaret, 2018a).

Results from the analysis is depicted in **Table 2** below; green denotes pooled interdependence, red denotes reciprocal interdependence. Note, firstly, that while sequential interdependence is not shown in the results, it is incorporated in reciprocal interdependence because of the Guttman effect (Thompson, 1967), and secondly, that practical exercises and simulations can give more insight into the development of interdependencies in air operations involving F-35 than theoretical analysis alone.

Table 2 Results from Analysis of Interdependence.

ACTIVITY	METHOD	AUTHORITY	ACTORS/UNITS							
			Strategic	NJHQ	NAOC	CRC	P-8	Frigate	JTAC	GBAD
AI	Autonomous		Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
	Network	Decentralized		Pooled	Pooled	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal
		Centralized		Reciprocal	Reciprocal	Pooled	Pooled	Pooled	Pooled	Pooled
ASuW	Autonomous		Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
	Network	Decentralized			Pooled	Reciprocal	Reciprocal	Reciprocal		
		Centralized		Reciprocal	Reciprocal	Pooled	Pooled	Pooled		
CAS	Autonomous			Pooled	Pooled	Pooled			Pooled	Pooled
	Network	Decentralized		Pooled	Pooled	Reciprocal			Reciprocal	Reciprocal
		Centralized			Reciprocal	Reciprocal			Reciprocal	Pooled
Strategic Attack	Autonomous		Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
	Network	Decentralized	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal
		Centralized	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal

Reciprocal	The activity gives reciprocal interdependence between F-35 and the given actor/unit
Pooled	The activity gives pooled interdependence between F-35 and the given actor/unit
	Level of interdependence not asessed/ unit not applicable in this type of activity

The results show a difference between interdependence in autonomous and network operations, and between vertical and horizontal interdependence in centralised networks. Note also the occurrence of reciprocal interdependence in strategic attack and the combined pooled/reciprocal interdependence in CAS-operations (we will discuss these results in more detail below).

For autonomous operations with F-35, we find the development of pooled interdependence between involved actors. Assisted by advanced sensors, F-35-pilots can find, track and target unidentified objects, identify these with help from on-board target libraries, and, if the target is within delegated authorisations, engage as appropriate. These activities can be executed without assistance from other actors in airpower roles included in the analysis (Laird, 2009). Consequently, a team of F-35s can solve tasked missions independently while still linked to the rest of the organisation through an overall objective for the operation (comprised of multiple missions). This supports pooled interdependence where different tasks are executed individually with no pre-set order (Saavedra, Early & van Dyne, 1993).

One prerequisite in pooled interdependence is the possibility of teams working independently, including control over necessary resources (Thompson, 1967). We find a possible (but temporary) exception to this requirement when autonomous operations are executed in dynamic environments. Fleeting environmental contingencies can provide a need for a pilot to gather information from other parties to adjust or enhance their own situational awareness. Looking at CAS-operations, where the situation on the ground is likely to be dynamic (Forsvaret, 2018a), updates might be necessary to ensure the safety of friendly ground troops. In this way, the transient influence of environmental contingencies can lead to a provisional increase in interdependence between F-35s and troops on the ground (JTAC). Pooled interdependence can still be supported, nevertheless: the pilot can achieve confirmation of the environment with a more silent information-gathering conduct with the aircraft's own sensors, information from the tactical link, or other means of communication (Lemons et al., 2018). This type of information-gathering is most likely unknown to other units and can be categorised more as a "passive" interdependence. If situational awareness cannot be achieved by means other than those of informal coordination, the mission can no longer be considered autonomous (NATO, 2018).

When complexity increases, operationally or environmentally, the need arises to execute missions in a network (Rico et al., 2018). Here we find more complex interdependencies – largely on account of the inherent nature of a network in which specialised teams will perform one or more network roles, so increasing the need for the exchange of information to ensure a shared situational awareness (Layton, 2017). Given our finding that the delegation of authority will influence interdependence, we will describe interdependence in a decentralised network before focusing on the centralisation of decision-authority.

In dynamic environments, the decentralisation of decision-authority can serve to maintain operational speed. Closer to the situation, the multi-team will be able to quickly adjust its actions by exploiting local information benefitting the decision process. Here, the F-35 team leader acts as decision-maker (among the other roles assumed in the course of the operation). In this model, we find vertical interdependence to be equal to autonomous operations, since decision-authority is delegated to the executive level. This supports pooled interdependence between the F-35 and the command level in a decentralised network.

Horizontal interdependence, however, is found to be more complex. To be successful in this kind of mission it is necessary to exchange more resources (information about weapons load, fuel status or ground/air movements, for example) to gain and maintain a shared situational awareness (Saavedra, Early & van Dyne, 1993). The level of interdependence will be decided by how flexible the involved actors are. If teams are very specialised, either based on their capability or decided by mission tasking, interdependence will be sequential, since one team will be dependent on the input from another (Skipper et al., 2008). If teams within the network are able to execute the different roles interchangeably, interdependence will be reciprocal. As an example, an F-35 and a frigate can both act as sensor and shooter in an ASuW-mission; additionally with the introduction of Joint Strike Missile, these actors can control each other's missiles after launch (Tørrisplass, 2018). Platforms are required to exchange resources in response to the situation's development. This can influence the mission more than once on the report of changing information such as target movements. Based on this, we claim the occurrence of reciprocal interdependence on the horizontal level in networks with decentralised decision-authority.

Interdependence will change in situations where (tactical) command level retains previously delegated TBMFs, or major changes require it to intervene in other ways so that shared understanding may be maintained (Lanaj et al., 2013). Environmental contingencies can also restrict the F-35-team's opportunity to contact others, either temporarily or throughout a full mission, meaning the mission must be executed in a so-called silent mode. In these cases, we need to look at other models to see how the organisation's decision-authority is formed and decide on the appropriate level of interdependence accordingly.

A centralised network can be necessary in politically sensitive situations or otherwise decided by the chain of command. Here, the F-35 team will act as sensor and shooter as the decision-authority is retained at the NAOC or NJHQ. In this construct, we find evidence of reciprocal, vertical, interdependence between NAOC and F-35. Such complex interdependence arrives from a need for continuous information exchange, since the executive actors will be closer to the situation and need to communicate developments that can influence decisions. In this situation, where the release of weapons, for example, can lead to new or updated mission-tasking, real-time information from the F-35 can influence the decision-maker throughout the mission. Horizontal interdependence will, on the other hand, be less complex, as NAOC will handle the overall situation with updated taskings. The specialised teams can adhere to tactical (or operational) level decisions and thus concentrate on their own speciality (role), investing less attention to the overall situation (Rico et al., 2018).

A final comment on the occurrence of reciprocal interdependence related to strategic missions is called for. We argue that the nature of the mission inevitably influences interdependence through the consequences of action itself (Forsvaret, 2018a). Strategic air operations will ultimately influence the whole organisation and using the F-35 as a strategic asset will generate complex interdependence.[6]

In summary, we find pooled interdependence in autonomous operations and both sequential and reciprocal interdependence in a network. In both operational methods, we find the influencing factor to be environmental contingencies which can temporarily alter interdependence both vertically and horizontally. The C2-structure can also control interdependence by delegation, or the retention of authority in strategic sensitive situations.

6 Considering the mission in isolation, interdependence is however as described above.

COORDINATION REQUIREMENTS IN AIR OPERATIONS WITH F-35

To answer which coordination mechanisms can most efficiently coordinate air operations with the F-35, we build both on our theoretical model and on our previous analysis of interdependencies. Returning to ***Table 1***, we find the different levels of interdependence relating to the most efficient coordination mechanism. In this light, regarding coordination requirements in air operations with F-35, we suggest the following:

1. Autonomous operations are most efficiently coordinated with the use of standardisation.
2. Network operations are most efficiently coordinated with a combination of formal and informal coordination mechanisms.

These statements indicate a need to integrate the full range of coordination mechanisms in the RNoAF (and the wider armed forces) to fully make use of the potential of the F-35. In other words, the flexibility of the air system in use must be reflected in the C2 construct. It is also important to take advantage of this flexibility when faced with a dynamic environment which can temporarily change coordination needs.

Mintzberg (1979) claims an organisation's use of the standardisation of tasks and work processes will ensure equality in the way tasks are solved and encourages both predictability and control in the organisation (Okhuysen & Bechky, 2009). Autonomous operations include delegation of decision-authority with the possible consequence of decreasing control in the C2 structure. The use of standardisation might help decision-makers regain a sense of control in situations where the F-35 is prevented from sharing information. Organisational knowledge of standards for planning, training and mission-execution (including CDE-levels and other rules) can contribute to the necessary level of trust and mitigate the feeling of lost control. Standardisation can thus ensure the inclusion of autonomous operations in the RNoAF's toolbox, as standard procedures can serve to assure the desired operational effect.

Because of its limitations in the processing of new information, formal coordination mechanisms might be most efficient in known and predictable environments. Since airborne platforms move fast and the environment is often highly dynamic (Forsvaret, 2018a), a high level of standardisation can attenuate operational effects in unknown situations. This also applies in autonomous operations, indicating the need to include the possibility of the temporary use of more informal coordination. Since, as Mintzberg (1979) points out, autonomous operations might be conducted in an environment where the pilot is prevented from sharing information, implicit coordination or mutual adjustment might be the best option. While the discovery of a temporary need to coordinate pooled interdependence with informal methods does not accord with Thompson (1967), it might indicate that autonomous operations will have (temporarily) higher interdependence, depending on environment – and serves as the basis of our claim that the C2 structure needs to be aware of changing conditions, and to understand how these conditions can influence interdependence if it is to predict coordination requirements.

In a network, interdependence is handled with a combination of formal and informal coordination mechanisms. When formal and informal coordination are used in combination, they will complement each other, so compensating for weaknesses (Okhuysen & Bechky, 2009). The size (van der Ven, Delbecq & Koenig, 1976) and the dynamic nature of a network point towards the use of informal coordination mechanisms. This need might decrease over time, when actors in a multi-domain environment become more familiar with one another's language and behaviour. Combined with shifting coordination requirements in autonomous operations, we find support for a needed flexibility in developing and using coordination mechanisms; the diversity of air operations applies, also, to the actors needed to solve them.

IMPLICATIONS FOR AIR COMMAND AND CONTROL

How, then, are these findings relevant to air C2? We will first focus on procedures and concepts before addressing possible structural arrangements in the command-structure; finally, we turn our focus to possible CIS architectures.

Procedures and concepts for fifth generation platforms focus on smartness and decision-speed; in a potential conflict with a technologically equal opponent, these can be decisive factors (Stephens, 2015). Our analysis shows that the development of flexible procedures can serve as a tool for the command structure to control interdependence and coordination needs in multi-team and single-team operations. More specifically, we highlight delegation of decision-authority as an important procedure in ensuring flexibility in future air operations. This is key, both in a flexible network and in autonomous operations, and we will further elaborate on the advantages and disadvantages of factors (increased risk-seeking, for example) the organisation needs to consider if it is to be successful in the development of efficient procedures (Lanaj et al., 2013).

Delegation of authority can have positive effects both on the individual and system level – an increase in flexibility and efficiency, for example. (Stea, Foss & Foss, 2015). This is due to the individual gaining the possibility of freeing up cognitive capacity for larger decisions as opposed to the micro-management of detailed actions on lower levels (Stea, Foss & Foss, 2015). In dynamic, multi-domain environments, this can result in more efficient OODA loops supported by local information. Additionally, the possibility of increasing the control of the continuous adaptation needed in a dynamic environment can confer advantages when facing a potential adversary through the motivation of units at lower levels (Stea, Foss & Foss, 2015).

As Stea and his colleagues (2015) have noted, at the individual level, the delegation of authority is positively correlated with high achievement, which can effectively increase operational effect. Through the active use of delegation, they note, the command structure can contribute to increased motivation: the trust individuals experience correlates to their professional knowledge. Others point to an increase in creativity, which can be useful when planning complex tasks in dynamic environments (Aime et al., 2014).

On the other hand, if the delegation of authority is not perceived to be credible, or not used at all, it can lead to a deterioration of performance, both individual and systemic (Hoeben, 2017). Delegation of authority can challenge coordination in an organisation, even cause coordination breakdowns (Stea, Foss & Foss, 2015). Coordination breakdowns can be caused either by a hidden interdependence or an evident interdependence the organisation chooses to ignore. This can result in an unintended use of a capability, serving to reduce the organisation's flexibility and thus cancelling the positive effects brought about by delegation (Stea, Foss & Foss, 2015).

To mitigate and avoid coordination breakdowns, the RNoAF should map interdependencies in the organisation of the F-35 system, thus maintaining the flexibility the system represents. At the same time, experimentation –through simulation, for example – could provide a risk-free setting for trying out novel use of the F-35. This experimentation should then be critically evaluated and linked to other activities.

Lanaj et al. (2013) suggest a link between decentralised planning and an increased acceptance of tactical risk. They further contextualise this finding with a tendency for more passive leadership in the coordination of decisions between components, leading to possible challenges in the planning of multi-domain operations. Cultural differences between domains contribute to a feeling of "us and them," which can further contribute to this acceptance of tactical risk (Lanaj et al., 2013). Here we find the principle of centralised planning and decentralised execution (Forsvaret, 2018a) to be an advantage in meeting this challenge. While this might reduce flexibility in the components during planning, this can be outweighed by reduced risk in the execution phase. Lanaj and colleagues (2013) also recommend the use of formal horizontal and vertical coordination to mitigate adverse effects of decentralisation. On this basis, we recommend the use of core groups and liaison elements to build multi-domain knowledge and culture in the organisation.

As we have seen, the delegation of authority needs to be credible if it is to produce the right effects in the organisation, and its use as an operational tool rests on willingness from any command level. Delegation will also ensure credibility in the use of autonomous operations. Autonomous operations are found to result in low interdependence and can be an important tool for the C2 structure to maintain a relative high decision speed. On the other hand, the method can challenge the C2 structure's feeling of control, especially if the F-35 team is not able to share information due to an operational high-risk environment. To counter this and to increase the possibility for decision-makers to choose such a method, we suggest the development of a strong framework. The framework should include circumstances when a team can, or should, stop sharing information. With such a framework, the C2-structure can decide if autonomous operations only will take place when pre-planned or if certain situations (i.e. communication break-down with a higher echelon or the appearance of certain time-critical targets) will give the team the authority to go silent (see Stensrud, Valaker & Mikkelsen, 2020).

We have here highlighted some factors which need to be considered when developing procedures for air operations involving the F-35. The incorporation of flexibility will be important in ensuring both the efficient use of F-35 in shifting environments and the ability to retain authority in strategic sensitive missions in early phases of crisis and conflict (Tørrisplass, 2018). Strategic operations might also present a need to skip one or more C2-levels in time-critical situations. Related to multi-domain operations, flexibility is also important – teams with different specialities might need to operate interchangeably.

Finally, the RNoAF should consider the balance between the potential of F-35 to achieve military effects towards exploiting a scarce resource. The RNoAF is a small air force where the training of single-domain pilots can be challenging. Our findings show that such a challenge might be met by mapping interdependencies to find how costly different missions are in terms of coordination-needs and requirements. Further, this can be used to see both where standardisation can be employed to reduce the cost of coordination and how flexible the C2 structure can be in delegation of decision-authority.

We turn now to personnel and structural arrangements in C2. Education, training and knowledge are all elements that can be influenced by the sheer complexity F-35 represents. They can also be affected by the mission-types F-35 can execute. The complexity in the system can be illustrated by the eight million strings of code that need to function if the F-35 is to be airborne (Yue, Kallonatis & Kohn, 2012). In addition, libraries which assist in the identification process and self-protection need continuous updates to ensure efficient and safe operations. While this study does not map interdependencies among these specialised support-roles, these are equally important if coordination breakdowns in the organisation are to be avoided (Thompson, 1967). A coordination breakdown can be mitigated by a shared knowledge within these developing value-chains when personnel discover their position in the larger picture of air operations. To guarantee the exchange of information, we suggest the development of horizontal constructs, including a diversity of perspectives in procedure-development (Mintzberg, 1979).

Knowledge of multi-domain operations will be of great importance in future warfare if the potential of F-35 and other fifth generation platforms is to be fully exploited. Horizontal configurations throughout the C2 structure will allow differentiated inputs to procedure-development to build on the entire organisation's situational awareness. This can serve to enable the use of airpower in a larger context. It can also lower the cost of coordination: the development of multi-domain standardisation can bring efficiencies across different mission types in complex environments.

To summarise, efficient multi-domain operations will be supported by information-sharing on the specific abilities of the F-35, thus potentially reducing the chance of coordination-breakdowns within the air force and in a multi-domain perspective.

Different mission types require specific forms of training and knowledge. While ISR has not had a lot of focus in this article, it is worth mentioning in this context. Through the execution of ISR, the F-35 has the potential to contribute with information to decision-makers throughout the C2 structure. This includes information from more contested areas. To translate information into timely, precise and relevant decisions, the armed forces will need personnel able to understand and process this information. To be useful, the information or intelligence needs to be made available to the right people at the right time. Implementation of the F-35 system can increase the need for personnel with these abilities in the C2 structure.

CIS permits the information exchange necessary if command levels are to maintain the speed of decision and operation required by a fifth generation air force (Forsvaret, 2018a; Forsvaret, 2018b). The analysis of interdependencies shows a need for information exchange, both vertically and horizontally, within the RNoAF, and among other domains. Involved actors will necessarily be required to act according to the discrete demands of the mission and the delegation of authority (see ***Table 2*** for an overview). This necessitates CIS being continually available if an operational tempo appropriate to a dynamic environment is to be maintained; it can thus support and ensure delegation of authority, since critical information can be made available on all levels. This will ensure a shared situational awareness and well-informed decisions, all the way down to the F-35 pilot (Kometer, 2005). On the other hand, the availability of CIS can also limit the delegation of authority, as it gives command-levels the possibility of what Creveld (1985) describes as a "directed telescope." In situations of strategic sensitivity, continuous CIS can also be very positive in ensuring a collective understanding in the organisation.

For handling interdependence and coordination requirements between actors in multiple domains, we find that CIS should be interoperable. This means both that systems can exchange information, and that the end-product (symbols and figures on a screen) have the same meaning across domains and C2 levels. This can decrease informal coordination-need if information exchange is based on pre-set standards. There will also be benefits for training, exercises, and operations with allied partners, as it will be easier to organise shared CIS solutions with technology founded on the same standard.

In the event of a conflict or crisis, the complexity and need for the exchange of information will most likely increase. In these situations, CIS needs to be robust enough to support the increase in both decision speed and the input of information (Yue, Kallonatis & Kohn, 2012). Since the F-35 can contribute to ISR operations, implementation can have a direct effect on the amount of information available for decision-makers in future airpower (Forsvaret, 2018b).

CONCLUSION

In this article, we have analysed interdependencies, environmental contingencies and coordination requirements in air operations with F-35 to discuss implications of the implementation of the aircraft in the RNoAF for the function of C2.

The F-35 offers the possibility of airpower more flexible in its execution and of further progress towards a multi-domain force. We find that the implementation of the F-35 leads to horizontal and vertical interdependence in the Norwegian armed forces. This interdependence varies with the operational method chosen and demands to be handled with a differentiated set of coordination mechanisms to ensure force flexibility.

The main challenge to the RNoAF C2 structure will be to avoid coordination breakdowns in the execution of air operations with the F-35. Mapping interdependencies in the organisation, we claim, will be vital in mitigating this risk. We further suggest C2 should incorporate and develop procedures for the delegation of decision-authority so as to ensure efficient autonomous and network operations. These procedures should, when applicable, be developed in a multi-domain environment to encompass diversity.

While multi-domain procedures can further influence the ways in which personnel work together (and we suggest more use of horizontal arrangements to accommodate the exchange of information and knowledge across domains and C2 levels), hierarchical arrangements should be developed as a component of the C2 toolkit, as they serve to limit excessive risk-seeking.

Finally, we find that CIS should support the highest level of interdependence: it will be too late to establish infrastructure for air operations when situations arise. CIS also needs, firstly, to be available to the command levels that require it, and, secondly, to support multi-domain interoperability. To ensure decision-speed and a collective situational awareness in the event of an escalation, CIS architecture needs to be robust enough to handle increased information-flow in peace, crisis and war.

There is still ground to cover and research to be done concerning the development of a national fifth generation air force. This article only covers a small piece of a much larger puzzle. It remains necessary to look at how C2 can handle the coordination of fourth and fifth generation air assets in an allied perspective and the nature of future battle management when the F-35 system can, to some extent, coordinate its own missions. What seems certain is that the implementation of the F-35 will affect the ways in which the RNoAF executes C2 of air operations in years to come.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Hanna Marie Bjerke
Royal Norwegian Air Force, NO
Sigmund Valaker *orcid.org/0000-0001-7562-1168*
Norwegian Defence Research Establishment, NO

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