ASTM AC377 AUTONOMY DESIGN AND OPERATIONS IN AVIATION

WHITE PAPER

ROLES AND RESPONSIBILITIES FOR OPERATIONAL CONTROL IN THE AGE OF INCREASINGLY AUTONOMOUS FLIGHT

IN THIS WHITE PAPER

CONTRIBUTORS

Mark Blanks, Wing

Stephen Cook, Chair, ASTM AC377

Jonathan Daniels, Praxis Aerospace Concepts International

Anna Dietrich, AMD Consulting

Tom Gunnarson, Wisk

Phil Kenul, TriVector Services

Andy Lacher, NASA

Adam Morrison, Streamline Designs

As the aviation landscape evolves with increased automation and autonomy, the traditional roles and responsibilities of operators, pilots, and other stakeholders need to be re-examined. In light of emerging technologies and systems, it is crucial to reassess accountability, authority, and responsibility of all parties involved in aircraft operations. In this context, this paper explores the current responsibilities of Operators (i.e., the entity responsible for initiating, conducting, and terminating a flight) and the impact of increasingly autonomous systems on the aviation industry. This paper addresses the changing nature of accountability and the potential for shared responsibility and accountability between operators, OEMs, and other stakeholders in this dynamic environment.

CURRENT OPERATIONAL FRAMEWORK

In an aviation context, an Original Equipment Manufacturer (OEM) builds products—such as hardware and software—and an Operator uses these products to conduct flight operations. "Operator" in this sense has a very specific meaning and is not a euphemism for a "pilot"; instead it is the organizational entity that exercises the authority for initiating, conducting, and terminating flight—an authority known as "operational control" as defined in 14 CFR § 1.1[2]. Operational control is accomplished through establishment of procedures, training, qualification of personnel, quality control of aircraft, and is typically exercised by pilots, dispatchers, and other personnel that are associated with the entity.

Organizational Operators take many forms ranging from airlines to air ambulance services to single pilot/aircraft operations. Regardless of the configuration, an Operator is charged with maintaining operational

[1] For simplicity, this paper's language is framed around United States operations, however individuals can also be operators and may hold several roles relative to the concepts under discussion.

[2] Per 14 CFR § 1.1, Operational control, with respect to a flight, means the exercise of authority over initiating, conducting or terminating a flight.

control over their flight activities. In essence, this means the Operator must establish a detailed framework for how, and by whom, operations are conducted such that safety and regulatory compliance are maintained throughout all phases of flight. In an air carrier organization (e.g. 14 CFR § 135 or 14 CFR § 121) the operational control framework is typically exercised by a tiered series of controls from strategic leadership—such as the Director of Operations and/or Chief Pilot—approving procedures and methods of operation for tactical implementation by certificated dispatchers and pilots who exercise direct control over individual flights.

In practice, an OEM will design, build, and test a product that subsequently gains design and production approval by aviation regulatory authorities with any applicable operational limitations. These products may come with a manual which describes the general use of the product. However, it is the Operator who must determine how the product fits within the organization's specific operations and then develop procedures and training for its safe and effective use within their environment. The Operator has discretion to determine when, where, and how flights may be conducted as long as they fall within the performance and regulatory limitations of the product and operation.

SHIFTING LANDSCAPE

Over the past decade, the increasing automation of aircraft systems has begun to shift the landscape of how aviation systems are operated in the national airspace. Standing assumptions based on direct pilot command and control for individual aircraft and direct oversight by operating entities are now routinely being challenged with systems that are able to shift elements of operational decision making from humans to automated system capabilities. This includes elements that range from flight planning to contingency management and everything in between. This increasing automation[3] now allows the potential for a single human being to safely oversee the simultaneous operation of numerous aircraft and handle only things that automation cannot process independently. Likewise, the health and safety of the Operator's aviation system/operation may now be monitored through automated tools and approaches that were previously impractical with non-automated operations.

Additionally, distributed or federated services, systems of systems, and the rapid introduction of automation to aviation including advanced technologies like artificial intelligence and machine learning are bringing innovations to an industry that prioritizes safety through deliberateness of change over speed of innovation. This manifests as a clash of cultures between technology developers, regulators, and legacy aviation stakeholders who perceive risks and responsibilities from dramatically different viewpoints. Another significant factor in this new risk-reward conversation is the overall opinion of the general public – from those who receive benefits from increasing autonomous aviation (e.g., drone delivery customers) and from those who may be averse to it (e.g., those who don't want drones flying over their houses).

Increasing automation of operational decisions, disparate approaches to risk management, and entirely new technologies raise questions and issues around existing assumptions regarding the role of an Operator (i.e., the entity operating an aviation system). The next section explores some of these

[3] It is beyond the scope of this paper to address the technical maturity of the technology associated with this shifting landscape.

challenges to highlight issues that need to be addressed to move this next phase of the aviation industry ahead; capturing the increased safety, efficiency, and use cases that autonomy can facilitate.

ISSUES

Moving toward a future where automation can make decisions and take actions that were previously performed solely by humans raises several issues to be considered. Typically, humans making operational decisions were affiliated with the Operator to include pilots, dispatchers, maintainers, etc. With the shift to increasingly autonomous flight, automation developed by OEMs will effectively be making operational decisions and executing actions that have traditionally been the responsibility of the organizational entity responsible for operating the flight. The following issues need to be considered:

1. Authority, Responsibility, and Accountability
2. Command Authority and Responsibility of the Pilot
3. Design Assurance vs. Operational Safety Assurance
4. Training, Qualifications, and Licensing

Issue 1: Authority, Responsibility, and Accountability

As automation takes on more safety-critical functions during flight, questions arise regarding which organizational entity is accountable for these actions. The shift to increased automation is likely to impact the authority, responsibility, and accountability of the Operator. Consider the following definitions from ASTM's 2022 technical report Regulatory Barriers to Autonomy in Aviation [4,5]

ACCOUNTABILITY

The obligation to answer for an action taken by a responsible entity

AUTHORITY

The power to give orders and/or make decisions.

RESPONSIBILITY

The obligation or duty to carry forward an assigned task to its successful conclusion; this is closely coupled to the authority.

In today's operations, automation is typically given limited authority and responsibility for very specific functions (e.g., fly-by-wire, auto-pilot, auto-trim). In many cases (e.g., auto-pilot, auto-trim) this authority can be revoked during flight by the pilot flying[6]. Throughout, the pilot in command remains accountable for all of the operational actions taken during the flight[7]. In general, today's automation is given the authority and responsibility for relatively straightforward tasks that don't require significant perception and judgment to execute. In the future, the complexity of tasks associated with automated decision-making is expected to increase significantly (Figure 1). In the future, automation may have significantly greater responsibility and authority to make decisions and act, delegated by humans.

[4] AC 377, Technical Report #3, "Regulatory Barriers to Autonomy in Aviation", 2022 ASTM.

[5] Ibid. As identified in AC 377 Technical Report #3, the term "liability" was determined to be out of scope and is therefore omitted from this paper.

[6] The pilot flying is the pilot operating the flight controls of the aircraft. FAA, Roles and Responsibilities for Pilot Flying (PF) and Pilot Monitoring (PM), SAFO 15011, 11/17/2015, https://www.faa.gov/sites/faa.gov/files/other_visit/aviation_industry/airline_operators/airline_safety/SAFO15011.pdf.

[7] 14 CFR 1.1.

This raises the question as to who is accountable; the entity that developed the automation or the entity that configured and is operating the automation?

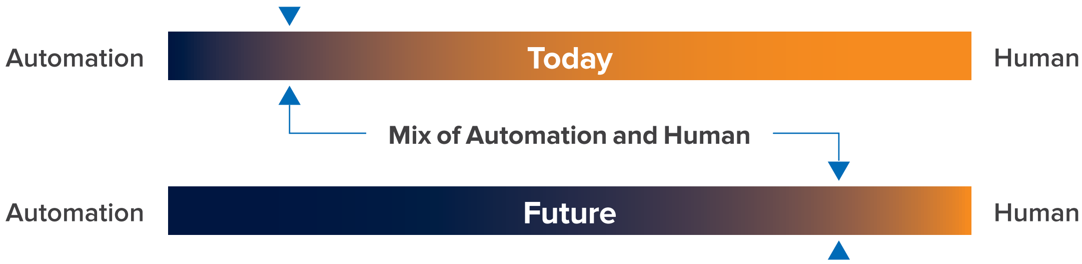

Figure 1. Notional Description of the Scale of Accountability for the Performance of a Function

In general, it seems logical that accountability can only reside with a human or human-based organizational entity. Through procedures documented in the Operator's operations specification, which is approved by the regulator, automation can be delegated the authority and responsibility to act. By today's regulations, the Operator is the entity that must maintain operational control, thus it would seem logical that they will remain accountable for those actions since they are responsible for procuring, configuring, maintaining, developing procedures for, and operating the automation systems.

For example, an Operator can delegate aircraft maintenance to a third-party organization. Today, Operators (e.g., airlines) often rely on third-party aircraft maintenance providers to perform a variety of maintenance tasks. The work that is outsourced can vary widely in scale and in scope, such as: servicing a particular component, overhauling an engine, or performing a D-check for an entire fleet of aircraft. Even when a task is performed by a third-party maintenance facility, the Operator is still responsible for the repair shop's compliance with the Operator's approved policies, procedures, and requirements. Thus, the Operator is still accountable for ensuring that the appropriate maintenance was performed.

If the Operator is accountable for operational decisions made by automation, they will need a mechanism by which they can ensure oversight and be able to provide guidance to the automation. In addition, some degree of transparency in how the automation makes decisions and how configuration changes impact its behavior will be required. The automation will have to be developed such that the Operator can appropriately configure it to adhere to their procedures as documented in their operations specification and be able to respond appropriately given the authority and responsibility which has been granted. Accordingly, the automation must be capable of meeting an Operator's procedures. The capabilities of a traditionally type certified aircraft are well known and documented, however the capabilities of an automated system may not be quite as clear depending on the method of design approval. There is some burden here on the OEM to define the limits of performance and capability of the automation they have developed.

Standards bodies like ASTM could lead the way in developing appropriate performance-based requirements and standard practices to guide manufacturers of automation systems that ensure that Operators are able to provide the necessary oversight and guidance. Standardizing this boundary between the creation efforts of the manufacturer and the operational obligation of the Operator is critical for clearly defining the authority, responsibility, and accountability roles and ensuring that the

Operator has appropriate transparency and can provide the necessary guidance to continue to fulfill their operational control obligations.

Some questions to consider:

– Who is accountable for operational decisions made by automation, the entity that created the automation or the entity that configured the automation?

– How should the interface between the manufacturer and the Operator best be defined for an automated system that makes operational decisions?

– What are the requirements for transparency and configurability of automation to ensure that the Operator can maintain operational control matching their accountability?

– Can automation be accountable or can only persons (consistent with the 14 CFR 1.1 definition)[8] be accountable?

Issue 2: Command Authority and Responsibility of the Pilot

During an inflight emergency requiring immediate action, only the pilot in command can make a decision to deviate from the rules and established procedures if they determine it is required to meet that emergency.[9] They are also accountable for explaining that decision.[10] How might this command authority endure as we increasingly automate flight operations?

Today, the Operator exercises operational control through the actions of humans who are hired, qualified, and trained to follow procedures established by the Operator which are consistent with regulations and are approved by the regulator. This includes the pilot in command and the pilots who are at the controls of the aircraft (i.e., the pilot flying). As routine aircraft control moves towards increasingly autonomous systems, the human role in the performance of many flight functions is increasingly reduced. In many cases, the human is over-the-loop, monitoring the automation system performing the function. The human can provide guidance and oversight that will impact the system behavior while automated processes have the authority to act without human actions or additional authority. Even with technology today, the pilot in command will likely remain accountable for the actions taken on the flight deck even if they are not the pilot flying. As automation matures, it can assume many—and potentially in the future, all—of the duties of the pilot flying, but not necessarily the duties, authorities, responsibilities, and accountabilities of the pilot in command, especially those related to deviating from established rules and procedures. It's important to note that in current regulations the authority to deviate from established regulations and procedures during flight is only given to the pilot in command, not to the Operator organization as a whole.

Predefined contingency actions could potentially be developed that deviate from rules and procedures. Perhaps predefined contingency actions can really be thought of as procedures to be included in an operational specification approved by the regulator? This would create the potential of Operator established contingency actions, where the Operator specifies the action in advance and thus potentially exerts authority over those actions, but not in a tactical sense.

[8] Per 14 CFR 1.1, Person "means an individual, firm, partnership, corporation, company, association, joint-stock association, or governmental entity. It includes a trustee, receiver, assignee, or similar representative of any of them."

[9] 14 CFR § 91.3b.

[10] 14 CFR § 91.3c.

As automation becomes more sophisticated, a clearer articulation of the line between control authority/responsibility/accountability and command authority/responsibility/accountability, could provide a path forward for regulatory approval while also potentially helping inform design assurance and operational assurance decisions. This is consistent with the recent European Union Aviation Safety Agency Opinion which draws a clear distinction between control and command authority and makes it clear "a human is always in command".[11]

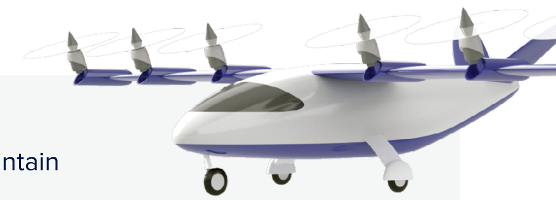

IMAGE COURTESY OF NASA

Some questions to consider:

- What situation awareness information must the pilot in command maintain as automation increases?
- How does the pilot in command remain in command if automation is effectively the pilot flying?
- How does the pilot in command exert command authority during flight for increasingly autonomous aircraft?
- How does command authority change if the pilot in command is responsible for more than one flight at a time?
- Does the pilot in command's authority have to be "real time"? To what degree can configuring automation behavior ahead of time be considered exerting command authority?
- Can the deviation from rules decision be made by the pilot in command a priori (i.e., by configuring the desired response before the event occurs)?
- To what degree can a pilot in command still perform their duties if they are not able to ever be in direct control of the aircraft?
- Can increasingly autonomous aircraft systems reach a point where a pilot in command is no longer required and instead the Operator exerts command authority through system configuration or other means? If so, can the "pilot" requirements in the operational regulations be effectively exempted in their entirety?
- To what degree can automation ever be given the authority to choose to ignore regulations (i.e., exercise 14 CFR 91.3b) or is that an inherently human role to execute command authority? Is technology mature enough to be programmed to appropriately perceive the situation and make the judgment to deviate from rules and procedures?
- As automation becomes more sophisticated, do we need to do a better job clearly articulating the line between control authority and command authority?
- How should operational requirements levied on the pilot be addressed?

Issue 3: Design Assurance and Operational Safety Assurance

As more operational decisions are being made by automation with less direct human involvement, there are more operational safety assurance processes that are now performed by systems. Traditional engineering system safety processes that are used for aircraft certification (e.g., ASTM F3230, SAE ARP 4761, SAE ARP 4754A[12]) and software assurance standards (e.g., RTCA DO-178C[13], ASTM F3201) may not

[11] Available from EASA, https://www.easa.europa.eu/en/document-library/opinions/opinion-no-032023
[12] Available from SAE International, https://www.sae.org.
[13] Available from RTCA, https://www.rtca.org.

conveniently translate to the realm of operational safety where operational experience and contingency management (e.g., adapting to traffic, weather) are key contributors to safety. In the aviation context, design assurance is the mechanism by which safety is achieved through the design, construction, and production of various systems (e.g., aircraft). Operational Safety Assurance is the mechanism by which safety is achieved through the design of processes and procedures for operational decision-making and the training and execution of those procedures. As operational decision execution shifts from a human-centric process to automation, some aspects of safety assurance that are currently part of Operational Safety Assurance will need to blend with aspects of Design Assurance.

Additionally, regulators typically rely on safety oversight systems such as implementing requirements for Safety Management Systems (SMS) among Operators and Original Equipment Manufacturers. Does the current SMS paradigm hold for increasingly autonomous aircraft systems, where operational decisions may be allocated to software? If operational procedures change (e.g., in response to a safety concern), how do these requirements flow to the air system and how does the OEM deploy the software update in an expeditious manner?

Without a clear path forward, there is a risk that progress towards increased safety and the greater utility of aviation will be stymied over concerns of "who is responsible?" if something were to go wrong related to tasks traditionally performed by the Operator or pilot in command which are now programmed into the aircraft and/or ground automation software.

IMAGE COURTESY OF NASA

Some questions to consider:

- Are existing software and design practices sufficient for highly automated systems that make operational decisions?
- Are operational procedure changes necessary for autonomous aircraft? How can we adapt current operations for new aircraft functionality?
- How can industry standards promote design assurance?
- Under what circumstances should automation be allowed to deviate from regulations? Who has authority in emergency situations when the pilot is replaced by automation?
- Would keeping the line clear between design assurance and operational assurance provide a path forward for approval?
- How can automation deviate from regulations without a pilot in command?

Issue 4: Training, Qualifications, and Licensing

Training, qualification, and licensing are other important areas that face challenges related to the increasing use of automation. For most aircraft operations today the pilot in command requires some form of certification that validates they are competent and qualified to safely conduct a flight; whether available certifications are appropriately scoped for increasingly autonomous aircraft is a question that needs to be collaboratively answered by aviation stakeholders.

Pilot certification is generally a tiered system where more complex operations require higher levels of pilot qualifications, experience, and training. Similarly, flight operations that involve the carriage of people or property for compensation or hire also generally require higher levels of pilot qualifications and medical fitness.

Similar to pilots, Air Carrier Operators conducting flights for compensation or hire are subjected to organizational certification requirements. Generally speaking, these are organizations with more than a single employee conducting scheduled service operations, cargo transport, external load operations, agricultural or other various types of commercial flights. Air Carrier Certification (e.g., under 14 CFR Part 135 and Part 121) requires mature processes and training programs and specifies clear roles and responsibilities for the people that comprise the Air Carrier organization.

For both pilots and Operators, there are rigorous certification requirements that span from knowledge and practical testing to organizational procedures, record-keeping, and ongoing training. Many of these requirements are rooted and designed with an assumption of not just human involvement in the regulator-accepted processes but of an individual human serving as the ultimately responsible party.

As automation is introduced and assumes some of the role of the human pilot or organizational Operator for completion of certain functions that are otherwise certificated, traditional training, qualification, and licensing processes are no longer appropriate.

Some questions to consider:

- As an example, if an airline transport pilot must demonstrate a minimum visual acuity within the prior six-month period to conduct a commercial flight operation, how does this translate to an automated system that does not rely on human sight?
- If automation systems solve a challenge traditionally addressed by pilot qualification or medical fitness through different approaches, are the relevant pilot qualifications or medical fitness no longer relevant? What requirements must these systems meet to be similarly certificated?
- If Operator certification requires specific “stick and rudder” skills for human crewmembers, how does this translate to automation systems for which human control input skills may have no safety benefit?
- What is the need for functional breakdown and splitting out of human and aircraft system knowledge, skill, and decision-making requirements that can be tested and approved?
- How will the diversity and potential rapid evolution of automation, along with the general opacity of complex systems, affect pilot training and qualification?

RECOMMENDATIONS

Increasingly autonomous aircraft systems and flight operations, enabled by emerging technologies, have led to a shifting landscape in which traditional assumptions and practices are being challenged. In this paper, we summarized the shifting landscape and identified four pertinent issues. Based on this work, the recommendations are:

A. Reassess Roles and Responsibilities: Given the evolving aviation landscape with increased automation, it is crucial to re-examine the roles and responsibilities of OEMs, operators, pilots, and other stakeholders. This re-assessment should consider the changing nature of accountability, authority, and responsibility in the context of emerging technologies and autonomous systems.

B. Clearly Define Accountability for Actions Taken by Automation: As automation takes on more safety-critical functions, it is necessary to clarify the accountability for operational decisions made by automation. While automation may have increased responsibility and authority, accountability must ultimately reside with a human or human-based organizational entity. Procedures should be established to delegate authority and responsibility to automation while system capabilities must be able to ensure oversight, transparency, and configurability to align with the operator's procedures and fulfill operational control obligations.

C. Establish Standards and Guidelines: Standards bodies like ASTM can play a crucial role in developing guidelines that ensure the necessary transparency and oversight by Operators so that they can fulfill their operational control responsibilities. Future and incumbent operators should be part of the standards-making efforts and can assist the standards bodies as they seek to develop guidelines in three recommended areas:

- Standards (performance-based requirements and standard practices) to guide automation system manufacturers so that they ensure transparency and configurability of automation and facilitate the necessary oversight and guidance by Operators.
- Standardizing the boundary between manufacturers and Operators to clarify authority, responsibility, and accountability roles, enabling Operators to maintain operational control and fulfill their obligations.
- Performance-based standards to identify methods for ensuring automation can perform the intended operational functions to acceptable levels of safety.

D. Address Pilot Command Authority: With increasingly autonomous aircraft systems, there is a need to clarify the command authority and responsibility of pilots. In this context, we should carefully consider and accordingly assign where the final decision authority resides, as high levels of automation may impact the pilot's ability to exert command authority. Any changes to pilot final decision authority will likely have an impact on operational control.

E. Assess the Existing Certification Processes: As operational decision execution shifts from a human-centric process to automation, some aspects of safety assurance that are currently part of Operational Safety Assurance will need to blend with aspects of Design Assurance. This would require a careful assessment of current certification, airworthiness, design assurance, and operational approval processes for systems, Operators, and personnel. This could include establishing consensus standards that 1) define additional performance-based standards for intended functions that were previously performed entirely by humans; 2) provide guidance/requirements for continued operational safety and maintenance for increasingly autonomous systems; and 3) redefine qualifications and training, if needed, for operational personnel.

F. Develop a Net Risk Assessment Framework: As the boundary between Operational Safety Assurance and Design Assurance blends together, there is a need for a framework in which total net risk impact and mitigation can be appropriately quantified. Strategic, tactical, and technical risk mitigations need to be accounted for, as do any risks that are being removed or introduced through the use of increased automation.

Moving forward, the aviation community can realize the promise of safe, increasingly autonomous aircraft operations through careful attention to the standards that will provide technical rigor and accountability for operational control.

ASTM INTERNATIONAL
Helping our world work better

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. We integrate consensus standards – developed with our international membership of volunteer technical experts – and innovative services to improve lives…Helping our world work better.

ASTM INTERNATIONAL HEADQUARTERS

100 BARR HARBOR DRIVE
P.O. BOX C700
WEST CONSHOHOCKEN, PA 19428-2959
USA

TEL +1.610.832.9500
FAX +1.610.832.9555
WEB GO.ASTM.ORG