THE MAN IN THE MACHINE: IS AVIATION'S WEAKEST LINK THE PILOT?

By Timothy Schultz and JP Clark April 14, 2020
https://warroom.armywarcollege.edu/podcasts/the-man-in-the-machine/

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JP Clark: Hello, and welcome to A Better Peace the War Room podcast. I'm **JP Clark** Deputy Director for Academic Engagement at the Strategic Studies Institute and a War Room Senior Editor. Whether civilian automobiles or military weapon systems, there is an ongoing debate about where to draw the boundary between human inputs and involvement and what to give over to machines. But some listeners might be surprised at how far back in time this discussion goes. To give us some historical perspective, we're joined today by **Dr. Timothy Schultz** an Associate Dean at the Naval War College and the author of *The Problem with Pilots: How Physicians, Engineers and Air Power Enthusiasts Redefine Flight.* Dr. Schultz is unusually well qualified to explore the nexus of science, technology and the military as he holds a master's in cellular biology from Colorado State, a PhD in the history of science and technology from Duke and is an experienced pilot having retired U.S. Air Force as a colonel after a career of flying U-2 and other aircraft. Tim, thanks so much for coming into the War Room.

Timothy Schultz: It is a pleasure to be here, JP, thank you.

JPC: Let's begin with the dilemma suggested by the title of your book, what is the problem with pilots, or more specifically, what was the problem with pilots in military innovation between the World Wars?

TS: Well as it turned out, their physical and cognitive limitations really stunted the potential of aviation. It wasn't long before the aircraft were able to fly to much greater altitudes and at greater speeds and get into an environment where humans just could not function correctly and humans became sort of a weak link or the limiting factor in terms of aircraft performance and this is recognized very early on by people like Lieutenant Hap Arnold who later, two decades later, was a five-star general in charge of the U.S. Army Air Forces. In 1925 he recognized that aircraft are exceeding and will soon exceed many of the capabilities of the pilots who operate them, and something needs to be done.

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JPC: Okay, very good. As historians obviously we don't want to put too much of the present upon the past but nonetheless, it is very interesting that we have these similarities and you have this period of galloping technological change its really pushing human abilities in terms of both physical and cognitive abilities and nobody really knows where it's going to end up in the end, a situation that exhilarates some people, terrifies others. In all of this, what is the role and what was the vision of engineers in this journey that we were undertaking?

TS: Well engineers, they had to learn new skills and a new way of looking at this technology if it was going to be operated by airmen, if it was going to have humans in it, and they needed to be able to account for those human limitations and how to maybe turn those into strengths or minimize their limitations and weaknesses where they could. Some of the major advances in aviation technology such as the development of instrument flight, they were heavily engineer centric. When Jimmy Doolittle flew the first blind flight in 1929, he relied heavily on engineers and he himself had a PhD in engineering and so he was kind of a hybrid between the two. When Lieutenant Albert Hegenberger in 1932 flew the first all blind solo flight, never seeing the ground but returning safely to it, it wasn't a triumph for pilots, just pilots, it was a triumph for engineers as well. And the same thing with Captain George Holloman in 1937, he took his aircraft off, released the controls and never touched the controls again. The mission flew around and landed again without him touching the controls, an extraordinary accomplishment for engineers. There were a lot of wrinkles in this though. Engineers had to learn how to compensate for the human cog in the machine because not all humans are the same, we don't come in standardized packages really.

JPC: Engineers would love if we were.

TS: And they actually tried to view pilots in that regard but there are immense variations in physical and cognitive characteristics that it was hard for engineers to account for. A historian that both you and I have read, Ivy Holly, coined this term called "design hubris" where engineers, if they fail to account for all elements of a system, thinking those different elements will naturally be able to mold themselves into what the engineers are creating, that's a form of hubris and we saw it in aviation development in the 20s and 30s, and in fact, we still see it today.

JPC: Okay, very good. One of the things that really struck me as I was reading *The Problem with Pilots* is one of the other key advances that is going on is high altitude flight. We get into pressurized cockpits and everything and the engineers really had to make some design trade-offs in order to accommodate the people. If the human was able to go ahead and keep on breathing at 40,000 feet, it would make the engineers job a lot easier. One of our current trends as we are talking about optional, manned, unmanned systems, but reading your book really made me think about how many engineering trade-offs are imposed by having the life support for pilot, crew, passengers, whatever, far easier if you just have a machine and you don't have to worry about the human element of it, and that creates some design trade-offs.

TS: Indeed.

JPC: So, with engineers expanding the technical boundaries…

TS: Can I add one point about engineers as well?

JPC: Yeah.

TS: Increasingly flight became more of this management of complex technical systems within the aircraft, the ability to fly at night or in bad weather, the ability to navigate, the ability just to maintain good aircraft control while still accomplishing mission objectives, and that shifted authority a little bit away from the pilots and towards engineers who could make all of these systems coming together so they were usable by the pilot. So, the pilots in some ways increasingly became more of the servants to technology rather than masters of it and they really had to rely on the ingenuity of engineers.

JPC: Interesting. Well, I think we'll see how some of that comes to bear later on in the conversation. As the engineers are expanding these technical limits, what's then the role of flight surgeons and scientists in this and these advances?

TS: I think flight surgeons have been kind of overlooked, sort of the unsung heroes of aviation development. They played a seminal role in the early 1920s and early 1930s in terms of integrating humans and their machines and this gets to really an essential part of the book. Pilots were at this leading-edge if you will or this cutting-edge of technological change where the human is being required to operate at extremes and to learn new skill sets and that informs, I think, some aspects of where we see technological improvements today and what they require for humans to do something different, or to behave differently, or develop new skills sets. Flight surgeons played this key vital role. I describe them as sort of engineers of the body. So, we have aeronautical engineers, mechanical engineers, we also have these engineers of the body or clinical pathologists of flight and they gained a lot of expertise and institutional power and influence in terms of determining who was fit to fly and how they are going to survive at the extremes of high-altitude or the extremes of high-G forces or at the extremes of low temperatures. And so, they played a vital role and an ingenious one in some cases. In the early testing of pilots in altitude chambers where they would reduce the air pressure inside of this tank where the pilot is so they could observe the effects of hypoxia and cold as well, they were studying that human element and somebody thought of the very clever idea of, let's take an x-ray of the pilot's chest and lungs while he is exposed to high altitudes and see what's happening physiologically and anatomically. So, they cut out part of the altitude chamber and replaced it with a type of metal that they could shoot x-rays through and had the pilot sit his back up against that inside the chamber and so they were able to take real-time x-ray images of how this environment was changing the pilot or how the pilot was trying to adapt to this environment. Probably their biggest breakthrough involved instrument flight though, and that was in 1926. There was this flight surgeon, an MD named Major David Myers, and nobody really recognizes his name today, but he worked with an aviator, an experienced aviator named William Ocker. They were doing these Bárány chair tests. The Bárány chair is a chair that spins around and if you're blindfolded, it will become very disorienting. And so, they were studying human disorientation and the physiology and anatomy of how the inner ear works had been worked out just in recent decades before then. A Nobel Prize have been given for that research, and so they were studying what's happening with pilots. Why is it when they fly into weather, they're getting disoriented? Why is it when a pilot flies into a cloud, he will observe that his instruments are suddenly going haywire? Well as it turns out, the instruments are just fine. They're not going haywire it's the aircraft, the pilot is going haywire and putting his aircraft into a graveyard spiral or becoming spatially disoriented. This flight surgeon Dave Myers and William Ocker, they realize that when pilots fly into a cloud and become disoriented or when they're flying at night and become disoriented, it's not because of a lack of skill of the pilot, it's because it's a normal human physiological reaction. That seems like a simple insight to us now, but in 1926 that was a classic paradigm change. It completely shifted the understanding of how humans can master the air and it opened up this whole new environment of instrument flight where you can do many more things in civilian and military aviation and that was the insight of a flight surgeon and his colleagues.

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JPC: You don't often hear flight surgeons being referred to as the pilot's friend, but they really were in this case and enabling, rather than simply—I don't know whether you had ever looked forward to any appointments with the flight surgeon but some of my other aviator friends not so much.

TS: I did. In my own aviation experience, the flight surgeon was… it was a see-and-avoid type of scenario. You want to see the flight doc as few times as possible and spend as little time as possible in his or her office because they have enormous authority and institutional power. They can ground you temporarily or permanently and there is a respect if not a fear of the flight surgeon, but there's so much more than that and particularly in the development of aviation in the 20s and 30s.

JPC: The cases that you've laid out show why this is not simply bad people keeping you from doing what you love, this is a fundamental aspect of making the human machine link up and system work.

TS: Yes.

JPC: The last element of your subtitle is airpower enthusiasts, and so course there are pilots who are enthused to be individually in the air but there's also generals and strategists who are enthused about building air forces and employing them for strategic effect.

TS: Yes.

JPC: So, this latter group, let's focus on them before we get to the pilots. What do they want from machines and what do they want from pilots?

TS: Many of the senior leaders in the U.S. Army Air Forces in World War II were pilots themselves. Hap Arnold learned to fly decades earlier. They were also pragmatists and they had a couple of different major goals in mind. One of them was institutional autonomy. They wanted to become an independent military service. They wanted to separate from the Army. They wanted to demonstrate the full capability of the aerial weapon and they pursued a lot of different avenues to do that. They also wanted to achieve victory. There was a strategic context which they were fully aware of and they knew that they would need to demonstrate the power of the air instrument. They determined that this doesn't always have to involve pilots or can involve pilots in different ways and in different roles and they also recognized that it had to. Again, it was a pragmatic approach. Hap Arnold in 1937 when the Army Air Corps was getting a lot of reports of needless accidents—accidents caused by carelessness and pilot error. Some of them were due to mechanical error as well. It angered him and he said we need to relegate the human flyer and elevate the mechanical pilot. Elevate the pilot who is able to rigorously follow the checklist, who is able to systematically conduct instrument flight not by the seat of his pants but by these newly established procedures and get away from the notion that human skill, human traditional, physical skill dominates. No, you need to have a new approach to expanding the potential of air power and that means integrating yourself with a machine and letting the machine do a lot of the work for you because it just does it better. Automatic pilots fly with much greater precision. Instruments let you navigate at night or in the weather. You cannot do it otherwise and when that realization really took hold, it did help improve the aviation safety record. Airpower leaders recognized this, and it also expanded the potential of what you can do and where you could send and how you can bring airplanes back.

JPC: This is kind of like with the engineers where they would love to have a standardized human cog, flesh cog in the machine. That way there's predictability in the effectiveness. I think particularly, as you point out in the book, the expansion of the Army Air Forces was so great, training tens of thousands of airmen a year, you're going to have a huge variation so much better. I'll lower the tenor of the discussion a little bit. In Star Wars Luke is going down and he turns off his computer and everybody goes, oh, that's fine, Luke turned off his computer. If Hap Arnold was in the command center, he would say, no, Luke, turn your computer on and be a standardized piece of this machine and I don't care about the force.

TS: That's right.

JPC: I want operational predictability.

TS: Putting the fiction in science fiction and to this notion of inexperience and this quantity of aviators but not a high-quality of aviators in World War II. There was an incredible demand for pilots and airmen in general, radio operators, navigators, bombardiers. General Ira Eaker lamented to a fellow general saying, these green kids, as he called them, they make mistakes you and I never would have made because of our experience. These tens of thousands of aviators, it's difficult to standardize them. I like to use the comparison of these old cannons that would explode. Back in the early days of artillery, you weren't quite sure of the metallurgical properties of that cannon and you didn't know under what conditions that cannon may burst and fail because there was variation. There's also variation in humans that is difficult to detect and under pressure, some humans will react differently than others. Some may burst and fail, and you cannot have that when they're flying a B-17 at 25,000 ft into the Reich. And so, again, that goes into the importance of flight surgeons helping to standardize, for engineers creating the conditions where those airmen can survive, and for the senior airpower enthusiast, forcing the young airman, these green kids to be as best trained as possible and for what they do, to be as rote and robotic-like and mechanical and predictable and checklist-driven as possible and it changed how airmen flew. It changed how they employed the air weapon.

JPC: Okay, so that’s a brilliant segway into our last element of the airpower enthusiast—we have the pilots. What does this change in the dynamic between the human-machine system mean for what it means to be a pilot both within the cockpit, in the most immediate sense, but also just more generally?

TS: I think that’s a vital question. When I was doing my research, I stumbled across this statement from a British flyer from 1918, and he said that the ideal flyer for our service is a youth of 18 who has been crossed in love. And he meant by that that hey, this is a dangerous business and you’re probably not going to survive it. That's not really sustainable and you can find ways to improve that with engineering, but it also required pilots to change how they approached operating this technology and what aviation really means. These conditions, these environmental conditions haven't gone away. The stresses of high-altitude or high-G or cognitive overload are still just as real today as they were in 1918 and in the interwar years and during the second World War as well. But they can be mitigated differently now. Pilots still have to have a same essential skill set. I take a lot of this from my own experience flying the U-2 and in my book, I rely on an experience that one of my fellow U-2 aviators had. Lieutenant Colonel Kevin Henry who is a hero among men, not only a great individual human being, but a gifted pilot. When he was flying a mission in the Middle East at high altitude, he had a severe case of decompression sickness and then also involved as he was trying to return to base some spatial disorientation, so the classic problems that have been associated with pilots since basically the Wrights flew or a little bit afterward. So, they're still extant. Some of those basic skills, the basic approach is the same, but flying along the way has become much more a management of complex systems. Pilots still have to be able to have a certain amount of stick and rudder skills, but they also need to bring together these different systems and make the aircraft or formation of aircraft work efficiently. I think I anger some of my fellow pilots with one of the lines, an opening line in one of the chapters, where I say, "a modern pilot is like the corpse at a funeral. His presence is expected but he really doesn't do much." But that is how it appears to be because pilots don't do much in terms of their physical control of the aircraft, in a typical sortie. And there are exceptions to that. If you're flying low altitude in an A-10 or helicopter, you're physically engaged. If you are landing a U-2, you're physically engaged, but in a lot of routine missions, in civilian airliners and in the military, you are observing the automatic instruments controlling the aircraft and you are there to manage those systems and to ensure safety and the mission is accomplished. So, that's a new way that pilots have to adapt. And it makes them more creative too. It lets them think of different things and maybe how to make the mission more effective rather than worry about maintaining altitude and air speed or the ability to land at night or in fog. It lets humans be more creative. Automation lets humans do different things. Flying is still a very human thing, but it's just done differently now. What pilots do has changed dramatically. If you look at the F-35, much of the information that comes into the helmet is displayed on the visor. It's oral, it's visual, it helps them manage the aircraft but as one F-35 pilot says, you see the world as the jet sees the world, you see the world through the jet's eyeballs, the sensors that are on that F-35. Your vision, your own eyeballs they're not as important anymore. It's what the jet is telling you and what the jet is sensing—that's what's important. And then you make sort of a cognitive assessment of those inputs that the jet has given you and then you make ideally the right decision as a pilot.

JPC: So, I was very taken by your description of how technology can allow humans to be more creative, but not necessarily everybody would see it that same way. Was there any resistance to pilots who felt like they were diminished because we are taking away from, to borrow the phrase from Tom Wolfe, that they weren't able to show their *right stuff* because the machine was doing too much for them?

TS: Yeah, and that's been an ongoing factor in pilot identity and cultural identity. There's an iconic image of the leather-jacketed, white scarf-wearing pilot, a macho personage. We get that. And that is extant to this day to some degree. After the breakthrough and this paradigm change regarding the necessity to fly via instruments, there were some pilots who resisted that. They thought that instruments were a crutch for less experienced, less talented, less skilled pilots, and it took a few years for that idea to really be ground down and to be eliminated. Pilots eventually realized, in order to operate this aircraft across its full potential, I need to become a good instrument pilot. I need to be what they called then, instrument conscious. I need to develop a good instrument consciousness where I can know at all times what the aircraft is doing, and the only way I can do that is to abandon my own five senses and trust these instruments that the engineers have designed for me to operate this weapon system. And so, they knew that they had to adapt in order to keep up with the potential of aircraft. It has some cultural implications as well and pilots will always revert to the ability to take control. I think that's probably a good thing regarding system effectiveness and efficiency, but even now, systems are designed where pilots, if they seize control, they still may be limited by the system in what they can do and how they can maneuver the aircraft such as in Boeing and Airbus airliners. Under the conditions of what they called normal law, the computer fly-by-wire system is still in charge. It won't let the pilot stall the aircraft or overspeed the aircraft or over-G the aircraft. There are limits on what the pilots can do, but there’s still an amount of pilot agency. Pilots realized that yes, they can't rely on the five senses, it's not all about them and their seat-of-the-pants instincts, but to be more effective, they had to adapt to these new abilities and embrace them. For some that maybe took a little longer than others.

JPC: So, that price seems to be a very pivotal moment in the evolution of the human-machine system in that, obviously the machine was important before, but once you have to abandon your senses like you say with instrument flight, then it's no longer a question of whether it's human or machine. At that point this where we put the cursor in between those because the pilot knows that they have to rely upon the machine.

TS: Yeah, there’s a blending there.

JPC: Yeah.

TS: As a pilot you have to behave in a machine-like manner in many ways, but you're also bringing something to the system that, short of general artificial intelligence, that the machine can't do. And we are a long way from the level of artificial intelligence that can replace the type of snap decision-making and situational awareness that humans can provide as a benefit in many systems. This leads us to today's debates about the degree of autonomy in weapons systems. As people say that we need to have, within lethal systems at least, there has to be human “in the loop” or human “on the loop” at least, those are driven by some engineering considerations but also a lot of it's about what we regard as legal and ethical which reflects society's values. What role does culture play in engineering and scientific endeavors?

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TS: I think in these engineering and scientific endeavors, in these technological developments, they're imbued by culture and by human agency. Even though some things are highly automated, most of an aircraft sortie is highly automated and the pilot provides very little physical control inputs. That doesn't mean that the pilot still doesn't retain agency and still isn't in charge, they're, in this case, in the loop. Another example of the in the loop and on the loop issue and how that is changing is consider an Aegis weapon system on a naval ship. If there's an incoming missile, if you have a human in that loop, then the weapon system won't reply in time. Humans are too slow cognitively, so it's automated. Instead, in that case, you have a human on the loop, one who authorizes the activation of that weapon system and lets it do its thing because it can do it much better than human cognitive or physical reflexes can. You see that in aviation as well. A pilot, although sitting in aircraft in the loop, he's also overseeing the loop, overseeing these automated systems as they fly and navigates in the most effective and efficient way as possible. But sometimes I think this whole in the loop and on the loop and out of the loop, I think it's a bad comparison or bad metaphor because humans invent the loop. They're involved at every stage. They write the algorithms. They provide the resources and the funding. They are shaped by their institutional dynamics and by politics and economic concerns. They hire and they fire. It's a very subjective enterprise, this whole notion of technological innovation. So, humans are part of that process all along. Now where it gets difficult is where do you sign human agency and liability and blame if something goes wrong? If someone is killed, how do you assess blame in that case when automation was involved? Do you blame the operator who was directly or tangentially involved? Do you assign liability and blame to the programmer? To the system director? To the institutional director? It becomes a little murky, I think, and we see how that debate is playing out today in terms of ethical accountability and legal accountability and those arguments aren't going to go away. That's something we're going to have to continue to work through.

JPC: And this is probably something that where military rules of engagement and military practices are probably going to be shaped by a lot of things that happened within the civilian sector as everything from self-driving automobiles and insurance companies figure out who they're going to go after, or all these other sorts of things. Society is having a larger discussion than just the military and it will carry over to us.

TS: It flows. It interconnects both ways. No doubt.

JPC: Indeed. We're running short on time, but one final aspect and this kind of gets into the conversation we were just having. As historians we know that history doesn't tell us what the future is going to be, but it can certainly arm us with the right questions to ask. So, based off of your deep understanding of military aviation between the World Wars, what sorts of questions should we be asking about human inputs, human involvement in machines in our own present day?

TS: That's a challenging question but it's one that we have to ask it and answer. I think that history is a laboratory where you can test ideas and test these questions and examine these questions. I think a good question to ask is how will autonomous systems and increasing autonomy, how will that let humans be more creative? We saw that with automatic fly control technology. It let airmen be vastly more creative. It let aircraft expand into a much wider range and diversity of missions. How might that play out in modern times? What's a modern analog for that? What will new advances in automation and autonomy let us do and will it make us more human by bringing out our creative side rather than our sort of functional physical operator side? That's a question that intrigues me and that this research alludes to. Another question is how will it change the nature of errors that are made? Captain Sully Sullenberger who was in the left seat when his Airbus landed on the Hudson, he was the hero of the Hudson. He talks a lot about automation in airliners as well and he recognizes that improvements in automation and more reliance on automation, although generally it's a good thing in terms of the safety record, it changes the nature of errors that are made. And if you see a change in the nature of errors that are made, that means there's a change in the nature of flight. There's a change in the nature of what's going on and we need to be cognizant of that. As Peter Paret would say, we need to try to gain intellectual mastery over technological change. And that is a difficult thing to do and I hope people keep writing articles and books that may illuminate the way forward.

JPC: Well, then that's a fantastic note to end this conversation. Dr. Timothy Schultz, author of *The Problems with Pilots,* this has been a great conversation and one that has taught me quite a bit, so thank you for coming into the War Room.

TS: I have learned much myself, JP. Thank you for this great experience and to everybody at the War Room.