A Concept for Next-Generation Combat Search and Rescue

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Introduction

The return of great-power competition means near-peer adversaries are challenging United States military superiority across many domains and missions. One of these missions is the ability to rescue aircrew shot down over hostile territory, a mission the US military calls combat search and rescue (CSAR). Currently, there is a gap as US military CSAR aircraft packages cannot follow advanced stealthy aircraft deep into areas with advanced air defenses. The gap has implications for the costs of air campaigns, aircrew morale, and even coalition operations as the US military has often provided CSAR support to allies. However, there are options to upgrade US CSAR capabilities. A combination of new equipment and a new concept for CSAR may give rescue packages the survivability and lethality needed to generate a reasonable chance of success, even against air defenses that could down a fifth-generation fighter. In this article, we will describe this new concept as well as how it might be tested.

The Problem

Today, the sophisticated air defenses of adversaries like China and Russia would make traditional rescue operations infeasible. The participants of a 2017 National Academies of Sciences conference on CSAR concluded that against near-peer adversaries, conventional CSAR was "highly unlikely to be viable."[1] Modern surface-to-air missiles can engage nonstealthy aircraft out to several hundred kilometers. The HH-60G—the current generation rescue helicopter—would not survive long against these threats, nor would the likely escorts of the fourth-generation nonstealthy fighters, such as the F-16, F-15E, or A-10. The net result of such a mission could be losing additional aircrew and their aircraft, producing a vicious cycle of more personnel to be rescued. Stealthy fifth-generation fighters (i.e., F-35, F-22) are more survivable in such an environment, but they are not invincible. Should any one of those advanced platforms be shot down deep inside the threat rings of an advanced air defense system, the aircrew could be on their own because the US military has no fifth-generation CSAR to go with its fifth-generation fighters. If fifth-generation aircraft could be spared from the larger air campaign as CSAR escorts, the vulnerability of the rescue helicopter itself would still jeopardize the mission.

History and Importance of CSAR

The US military's CSAR capability first took shape in World War II but in a limited form. Most successful rescues were via submarine or seaplane, of aircrew on the water or at the shoreline. US forces alone rescued few personnel inland.[2] Aircrews shot down over German-occupied Europe could still be rescued but only with the assistance of third parties (e.g., the French resistance) over much longer timelines than with conventional CSAR missions and at a relatively low rate of success. A preview of CSAR's future on land was provided in April 1944 in Burma, when the US Army conducted the first helicopter rescue of an American pilot, using an early prototype Sikorsky YR-4.[3]

In the Korean War, CSAR expanded its geographic scope with US forces able to regularly rescue personnel inland. The helicopters were crude by today's standards and available in small numbers, but they gave commanders a new inland rescue capability. Even at this early stage, helicopters brought home 60 percent of United States Air Force personnel rescued during the war.[4] The US military developed many of the CSAR basic principles and functions during this period. During the Vietnam War, CSAR evolved further into what many are familiar with today. That CSAR capability carried the US military into the twenty-first century, including the long counterinsurgency campaigns in Afghanistan and Iraq.

But for a few notable exceptions since the Korean War (e.g., Hanoi, 1972; Baghdad, 1991), US military commanders have had viable options for recovering their downed aircrew. Knowing that recovery assets were in place increased US and partner nation commanders' willingness to send aircrews on higher risk missions while also benefiting aircrew morale. A CSAR system without the ability to penetrate advanced air defenses could strain coalition coordination with some partners opting out from risking the enemy parading their pilots as trophies. Moreover, the expensive and time-consuming process of developing aircrew capable of operating America's best aircraft make those personnel important and difficult to replace. High-tempo operations, absent a robust CSAR capability, could result in substantial personnel losses that could take years to replace. During a prolonged conflict, the impact on operations from pilot shortages (from all causes) could be profound; this happened when both Germany and Japan could not maintain their supply of trained and experienced aircrew late in World War II.[5] This is not to say pressing on with an aggressive air campaign would be impossible despite the lack of a viable CSAR capability, but it would raise the costs.

A New Concept

The US Air Force launched *Agility Prime* in April 2020 to accelerate the era of electric vertical takeoff and landing (eVTOL) aircraft for military and commercial use, and CSAR could be one possible military use of these vehicles.[6] The program could accelerate fielding platforms important for advanced CSAR, but the Air Force still needed a concept for employing them. The authors have an initial framework for such a concept built upon three central pillars:

- Risk no additional personnel during a rescue.
- Do not pause the larger ongoing air campaign, nor draw significant resources away from it.
- Conduct the rescue rapidly, within a few hours if possible.

For context, a conventional rescue package could include several helicopters and approximately half a dozen fighter aircraft to deal with air defenses and other threats to the downed aircrew (e.g., enemy vehicles and infantry). The exact composition of any package would vary, customized by commanders to address each mission's needs, along with the assets available at that time. CSAR missions would sometimes include aircraft for protection against opposing aircraft, depending on enemy capabilities. However, our concept will not discuss this element as it would likely not differ from how fighter cover is provided for current CSAR missions and use the same existing platforms (i.e., F-22, F-35).

In contrast, we envision a much larger rescue formation, composed solely of unmanned systems, at least until any recovered personnel are aboard the recovery vehicle(s). The formation includes many more aircraft than a conventional package (63 aircraft total, 60 escorts plus three recovery vehicles), to dramatically increase the formation's ability to take losses while maintaining the ability to accomplish the mission, putting no additional personnel at risk.

None of the aircraft in the formation need a runway, which allows for the rescue formation's aircraft to remain dispersed because they no longer need to concentrate around a few airfields, which tend to be high on an enemy's targeting list. This independence from runways also aids response time because these aircraft can be based close to the front line.

Note: the platforms we describe illustrate the needed platform characteristics but should not be considered the only possible solutions.

As our focus is on the challenges of CSAR in high-threat environments, the rescue formation described is optimized for that environment. In the future, the US military would certainly conduct CSAR in a range of environments, so our described formation is intended as a compliment to existing CSAR capabilities.

New Rescue Package Characteristics

A key technology behind the concept we propose is a repurposed all-electric urban air taxi aircraft—a type of aircraft that the aviation industry has matured rapidly in recent years. During the last few years, the capital markets have been investing hundreds of millions of dollars into a number of commercial research and development efforts on flying electric urban taxis.[7] Advances in electric propulsion, battery technology, and autonomous flying has spurred a broad push across the aviation industry to be the first to market. Battery prices have fallen 87 percent from 2010–19, reducing platform cost.[8]

Perhaps an even stronger motivation has been the potential for dramatic reductions in operating costs. Data from 2018 for the New York City government's fleet of vehicles showed annual maintenance costs alone (not counting fuel) were approximately 80 percent less when comparing similar-sized all-electric vehicles to vehicles with internal combustion engines.[9] Most developers of flying taxi designs envision the pilot being replaced by autonomous flight capability at some point, further reducing costs.

Most flying taxi designs in development are ill-suited to a rescue mission inside hostile airspace; they are generally slow, short-range quadcopters, optimized for short hops around a city. But some commercial technologies show promise in potential military applications. For example, a German company, Lilium, envisions a taxi capable of flying between cities. In flight testing, now with an estimate in-service date of 2025, the Lilium Jet (fig. 1) is designed to fly 300 km at 300 kph.[10] It achieves this higher speed and long-range by dispensing with the usual large, exposed rotors and instead using 36 small basketball-sized electric fans, each nested in its own nacelle and arrayed in rows along the front and rear wings. The rear wing is fixed; only the row of engines along the trailing edge rotates for vertical flight. The entire front wing rotates for vertical or horizontal flight. This design allows the wings to provide the lift in horizontal flight, freeing the engines to provide forward thrust. The Lilium Jet is designed for four passengers plus one pilot, with the long-term goal to replace the pilot with an autonomous flight capability.

Figure 1. Lilium Jet

Table 1. Electric air taxis—comparison of desirable characteristics

Characteristic	*Commercial Mission*	*CSAR Mission*
Low noise	Valuable	Valuable
Low operating cost	Valuable	Secondary
Speed and range	Valuable for city-to-city	Valuable
Low heat signature	Irrelevant	Valuable
Lower radar cross section	Irrelevant	Valuable
Autonomy	Valuable	Valuable

There are no indications the Lilium's designers envision any military applications, but the commercial urban taxi mission has several requirements that overlap with CSAR. For example, the Lilium is designed for quiet operations over urban areas, which also happens to be valuable for CSAR. In some cases, the needs of the commercial mission produce accidental benefits for CSAR. An example would be the electric propulsion system that the commercial users want for its low operating cost, while CSAR operators value the low heat signature that comes with that engine type. See table 1 for a summary of mission characteristic comparison.

The escorting platforms for the rescue package could be several models of in-service long-endurance loitering munitions. The Harop is a long-range loitering munition built in Israel, designed to target air defense systems, capable of flying up to 400 kph and 1000 km.[11] The Harop includes a sensor for detecting radar emissions along with an optical sensor to confirm targets, but a human operator commands any attack. The small 40 lb. warhead in the fuselage does not detach, so to destroy a target, the Harop must dive into it. Though not necessarily expendable, if no targets are found it can return to its launch point for recapture and refueling. The Harop launches from a truck with its wings folding out to their full 3 m span after launch. For the rescue package, the Harops would be focused on suppressing enemy air defenses.

The Hero 900 is another Israeli-made, long-range loitering munition but slower, smaller, and with a maximum range of 250 km. Also, truck-launched, it carries an optical sensor and small 20 kg warhead, can be recovered after launch, and has a human operator controlling any attacks.[12] The Heroes in the rescue package would deal with both air defenses and threats like ground vehicles or patrols that threaten the recovery vehicle or downed pilot.

Both loitering munitions depend on communication links back to human operators for executing attacks. Were those links lost for extended periods of time, this would sharply reduce the effectiveness of these munitions. The viability of US communications to support the use of these escorting munitions is a key question for this concept and should be explored further.

One possible solution would be equipping these munitions with an autonomous attack capability, something they currently do not possess, at least per open sources. Adding such a capability would involve two challenges: technical and policy. We suspect that the policy challenge is the greater of the two, considering the impressive capabilities of the current generation of smart munitions. US policy does not specifically prohibit lethal autonomous munitions. Department of Defense (DOD) Directive 3000.09 requires that autonomous and semi-autonomous systems "shall be designed to allow commander and operators to exercise appropriate levels of human judgement over the use of force."[13] With the DOD's historical sensitivity to civilian casualties, defining that a lethal autonomous system meet that standard of "appropriate levels" standard would be difficult.

The rescue package's design would resemble a conventional rescue package in function but differ in platforms. For comparison, consider a notional rescue package composed of two HH-60 helicopter recovery vehicles, four A-10s to deal with various ground targets, and four F-16s focused on enemy air defenses. Every CSAR mission is different, but this gives a baseline for comparison. If one were to design an unmanned package that was roughly equivalent, using the previously mentioned platforms, that package could include three Lilium recovery vehicles, 12 Harops, and 48 Heroes. In this composition, we are aiming to roughly replicate the functions of the manned package. The large number of munitions on the escorting manned fighters requires a large number of escorting drones since they carry only one warhead each. See table 2 for a summary of the two rescue package designs.

Table 2. Comparison of rescue packages

Package Type	*Platform*	*Role*
Conventional, Manned	2x HH 60	Personnel recovery
	4x F-16	Suppress air defenses
	4x A-10	Protect pilot and recovery vehicle
	Total: 10	
Unmanned	3x Lilium Jet	Personnel recovery
	12x Harop	Suppress air defenses
	48x Hero	Protect pilot and recovery vehicle
	Total: 63	

The key advantage of the unmanned package is its ability to absorb substantial losses and still retain its core functions; we assumed such losses during its fight to the pickup point. Escorting drones attacking threats that could not be bypassed would suffer some losses, others would be to undiscovered pop-up threats. We also assumed two parameters for each rescue mission: 1) that the larger air campaign would have revealed some enemy threats, and 2) that additional threats were certain to exist. Thus, the rescue package was designed to feel its way forward, paying for information with lost platforms. That dynamic is key; the unmanned package can afford that cost where the smaller manned package cannot.

Because the 60 escorting drones carry both sensors and warheads, although both of modest capability, this creates a dilemma for the enemy: accept the risk of an approaching drone discovering and destroying a valuable asset needed for the larger conflict or engage and risk revealing the asset's location. In the context of the larger conflict, enemy forces will be dealing with other threats, such as a wave of F-35s, that may follow shortly after a rescue package, so they will have some difficult choices. Is a package of relatively low-cost recovery vehicles and escorting drones worth risking detection by firing or depleting precious surface-to-air missile inventories? In terms of the larger conflict, losing an inexpensive drone to a top-of-the-line Russian S400 missile would be a win for the Blue team.

Testing the Concept

This concept is immature and needs testing against the spectrum of threats a near-peer can present. Portions of the concept may be flawed, or the entire concept may be found wanting, but we see the combination of need and promise as making such an effort worthwhile. Below is a list of questions we see as key to better understanding the concept's viability, which could be explored via war games and experiments.

- What is the interplay between Red electronic warfare capabilities, drone autonomy, and US policy on lethal autonomous systems?
- What are the communications and navigation challenges (e.g., bandwidth, personnel) for coordinating the many platforms in the rescue package in a hostile electromagnetic environment?
- What is the cost trade-space between advance air defense munitions and the platforms in the rescue package?
- How effective would less-advanced air defenses (e.g., man-portable surface-to-air missiles, radar-guided artillery) be against the unmanned rescue package?
- How would this CSAR capability impact the larger Blue air campaign, and vice versa?
- What is the relative value of various performance characteristics (e.g., speed, stealth, lethality, sensors, range, cost) for the platforms in the rescue package?

- How sensitive is the overall rescue package performance to changing mission variables (e.g., number of personnel down, terrain, distance into enemy territory, weather)?
- What is the utility of decoys in the rescue package?
- Where are the most effective Red counters to such a rescue package?

Conclusion

While the nation's best aircraft offer impressive capabilities against advanced air defenses, one cannot forget the crews that operate them. To preserve that critical human capital for whatever conflicts the future holds, the US military's CSAR capabilities should evolve for the new threats. This evolution is possible if existing capabilities are augmented with specialized rescue packages that are unmanned, larger, and can sustain much higher losses while retaining effectiveness. Loitering drones for escorts, plus eVTOL recovery aircraft, could provide the needed hardware. The concept described in this article, combined with that hardware, could give future CSAR missions a fighting chance in even the highest threat environments. ✪

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Notes

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