A Hiller VZ-1 Pawnee Flying Platform demonstration in 1958. (Photo courtesy of the National Air and Space Museum, Smithsonian Institution)

Raising the Bar

The Future of Individual Lift Devices in Warfare

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In 2013's *The Great American Jet Pack*, Steve Lehto asserts that the idea of personal flight is a mirage, continually eluding the clutch of technological advancement.[1] This article assumes that this assertion is incorrect; instead, it contends that advancements in individual lift (IL) technology are bringing human flight within reach. At some point in the not too distant future, mature IL technology will enhance a military force's ability to conduct distributed maneuver, undermine anti-access/area-denial (A2/AD) defenses, augment autonomous systems, and defeat adversaries in complex terrain. Thus, military planners must better prepare for the integration of individual lift devices (ILD) into existing systems and future programs as well as develop methods to counter an adversary with an advantage in IL technology.

The IL technology development over the last century has been sporadic and underwhelming. From 1940 to 1983, IL technology promised a revolution but delivered merely impractical novelties. The expectations of flying shoes, platforms, ducted-fan lift devices, rocket belts, and jet belts always exceeded the technological limitations of that time.[2] Similarly, progress since 1983 has been unremarkable, stymied by reduced corporate and military research into ILD.

That said, sporadic, small-scale development has continued, primarily by entrepreneurs impassioned by the futuristic vision advanced through popular science. A modest resurgence in military and corporate interest and investment is now apparent and has the potential to advance IL technology beyond science fiction. However, for promising international developments in IL technology to eventually succeed, civilian and military proponents must overcome skeptical views of ILD.

Defining Individual Lift Device Terminology

There is a broad variety of technology that is categorized using the ILD terminology. For this article's purposes, the following generic definition of ILD is used: any physical device below the level of a conventionally sized airframe capable of safely transporting one or two soldiers through the air domain. This definition deliberately avoids limitations of control mechanisms, elevation limitations, payload, and range requirements to allow for a broad understanding of the impact of IL technology on warfare. Defining methods of ILD control is also relevant: kinesthetic control uses human body movement to direct the lateral control of an ILD, whereas electrically or mechanically controlled methods employ componentry to direct flight.

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History

In 1958, the U.S. Army encouraged ILD research to augment soldiers' abilities to jump and run. At that time, the Army sought a solution by requesting industry to create a backpack-mounted device to move 160 pounds "applying small rocket lift devices" for more than fourteen seconds.[3] Respondents offered two divergent approaches. One employed short-burst rockets to cross obstacles. Another, Bell Aerosystems, advocated limited free flight and delivered a prototype capable of thirteen-second untethered flight.

A subsequent review assessed Bell's project as "highly successful," but its potential was deemed limited by flight duration, noise, and specialized fuel requirements.[4] As a result, the Army-sponsored project was canceled. Despite the project's cessation, Bell continued development and in 1965 secured funding for an alternative solution. The "jet belt" was a turbine rather than a rocket-propelled device.[5] Although not successful in the United States, development overseas offered renewed promise. Sud Aviation, a French company, applied to patent an "augmented thrust rocket system" in 1960 that increased range by increasing fuel efficiency. In 1964, the French army contracted Sud to develop a prototype that enhanced a soldier's ability to "leap over obstacles." The requirements included moving 263 pounds over "several hundred meters" below a fifty-meter ceiling. Despite successful tethered flights, Sud was unable to exceed forty seconds of flight. This shortfall, combined with concerns about noise, led Sud to cease development.[6]

Nevertheless, concurrent advancements in turbojet and turbofan technology led other developers to pursue jet-powered ILDs. For example, the Defense Advanced Research Projects Agency funded Bell and Williams Research in 1966 to develop a new turbojet-powered jet belt for the U.S. Army. However, Bell eventually withdrew from the program citing costs; a suitable engine alone was projected to cost approximately $85,000. Undiscouraged, Williams Research promoted the turbofan as an alternative to turbojet technology, convincing the U.S. Marine Corps (USMC) to support development under the Small Tactical Aerial Mobility Platform (STAMP) program.[7] In response, the Marine Corps stipulated a requirement for a "simple and highly reliable" low-altitude platform to complement existing systems, lifting five hundred pounds over nineteen miles in thirty minutes.[8] The platform was to be a conventionally fueled, helicopter-transportable ILD with a mandated "emergency descent capability from low altitude."[9] The ILD was also to be employable and serviceable by tactical units with limited training. Regrettably, tethered tests of the Williams Aerial Systems Platform (WASP) failed to meet design specifications, and in 1973, the program was also canceled. Not to be deterred, the Army pursued another ILD program, the Small Tactical Aerial Reconnaissance System-Visual (STARS-V) program.[10]

In 1977, the STARS-V program funded two simple WASP II prototypes.[11] By 1983, the prototypes did not meet expectations. Unfortunately, the Army's requirement for simplicity of operation encouraged Williams to return to kinesthetic controls for the WASP II, resulting in a "directionally unstable" platform susceptible to wind gusts and requiring "extensive pilot compensation." Though capable of safe flight within the fifteen-foot altitude test limits, the prototypes required fitment of a parachute, were noisy, and were only capable of five minutes of flight.[12] Moreover, they had an anticipated cost of $250,000 per unit.

During the same period, the Piasecki Aircraft Company proposed an alternative approach—one not selected for development at the time but prominent in today's ILD projects. The Piasecki proposal employed "rotating combustion engine-ducted propeller[s]," that is, four ducted fans powered by twin lightweight, low-cost, low-noise, and fuel-efficient engines. Of note, the initial prototypes exceeded the payload, speed, altitude, and duration requirements.[13] However, the Marine Corps rejected the proposal at the time due to the complexity of the controls and aircraft weight.

Nevertheless, the Piasecki proposal anticipated the developments of today's current ILD technology, including the Malloy Aeronautics Tactical Reconnaissance Vehicle (TRV), sponsored by the U.S. Army Research Laboratory, which is currently undergoing testing and evaluation.[14]

Malloy originally developed the TRV as a "hoverbike" or "flying motorbike."[15] During feasibility and development testing, it evolved into an unmanned logistical vehicle known as the Joint Tactical Aerial Resupply Vehicle (JTARV).[16] The JTARV is a battery-powered or gas-generated, electric-controlled, autonomous platform propelled by four rotors with three hundred pounds of payload capacity.[17] The initial idea was for this ILD to be unmanned; however, the potential for a platform capable of lifting several hundred pounds, coupled with an endorsed feasibility concept for a manned TRV, has showcased a significant advancement in IL technology.[18] The TRV is just one example of rekindled worldwide increase in ILD research and development fostered in large part from the commercial development of unmanned aerial vehicles with payload capacities exceeding the weight of combat-equipped soldiers. For example, Martin Industries is a publicly listed New Zealand company that has produced advanced ducted-fan ILD technology. In an ongoing partnership with the Chinese Kuang Chi Corporation, they have successfully conducted manned and unmanned test flights of an optionally piloted hovering air vehicle, achieving 265 pounds of lift, a speed of sixty miles per hour, and thirty minutes of flight.[19]

Additionally, Dubai funded the Chinese firm EHang Inc. to develop a drone-based aerial public transportation system using a German-manufactured Volocoptor as the basis for an autonomous air taxi system.[20] Dubai police have also undertaken a memorandum of understanding with Russian developer Hoversurf to produce "hoverbikes" for emergency responders.[21] In September 2017, Russian defense manufacturer Rostec announced its "flying car," an electric battery-powered, ducted rotary-fan platform.[22] Also, Boeing has sponsored the GoFly Prize competition to develop "safe, quiet, ultra-compact, near-VTOL [vertical take-off and landing] personal flying devices capable of flying twenty miles while carrying a single person."[23]

Furthermore, JetPack Aviation (JPA) has developed and tested autonomous and manned ILDs including jetpack and stand-on platform models. This U.S.-based company has a Federal Aviation Administration-accepted turbine-powered jetpack in production. It is also designing a ducted-fan model and an aerial resupply system—the Self Hauling Remote Payload Apparatus

The Army's experimental one-man helicopter during a test flight in 1957. The De Lackner DH-4 Heli-Vector was later redesignated and renamed HZ-1 Aerocycle. (Photo courtesy of the U.S. Army Transportation Museum)

(SHRPA)—and are working with the U.S. Special Operations Command (USSOCOM) under a cooperative research and development agreement to develop ILD for special operations applications.[24] However, all of this development has not yet engendered significant military interest, ideas, or funding.

Considering Military Applications of Individual Lift Devices

Legitimate skepticism derived from decades of overpromising and underdelivering IL technology remains an obstacle to a fair assessment of the military applications of ILD. A realistic evaluation, however, should serve to remove continuing doubts. Current commercial developments in IL technology and ILD demonstrate the feasibility of this concept. Therefore, renewed study of the military potential of ILDs (and development of counter-technologies) is warranted. Since reinvigorated commercial investment and interest has propelled ILD from the realm of science fiction to reality, the services and supporting military institutions must set aside historical skepticism and conduct an impartial assessment of the current feasibility of employing IL technology in future warfare. There are four key potential areas to be studied relative to military application in future warfare: enhancing distributed maneuver, undermining an adversary's A2/AD defenses, augmenting autonomous systems, and enhancing the ability to defeat adversaries in complex terrain.

Distributed maneuver. ILDs could provide a great competitive advantage to militaries that employ a distributed maneuver concept. The *Marine Corps Operating Concept* advocates distributed maneuver as it "avoid[s] the disadvantages of mass when required and employ[s] the benefits of mass when operationally favorable."[25] The low signature and highly flexible nature of ILDs could allow military forces to aggregate and disaggregate at speeds that far exceed existing capabilities. This versatility could be used by reconnaissance forces to penetrate an enemy's defenses with minimal risk of detection or in advance-force operations to seize initial objectives.[26] Though the force protection limitations of current ILDs prevent their use as main assault forces, such limitations as reduced armor protection do not preclude the use of ILD as a method of clandestinely maneuvering assault forces toward an objective. An example is a movement by ILDs from offshore vessels to intermediate transfer barges or to lightly defended objectives during amphibious operations. Another example is the movement of forces in rear echelon areas or to rendezvous with protected mobility platforms.

A turbine-powered individual lift device designed to take off vertically and enable a man to fly for thirty minutes at speeds of up to sixty miles per hour has been successfully flown in a series of free flights by military personnel. It is known as the Williams Aerial Systems Platform (WASP II). The WASP II was considered as a candidate individual lift device by the Army and the Infantry Board in the 1980s. (Photo courtesy of the U.S. Army)

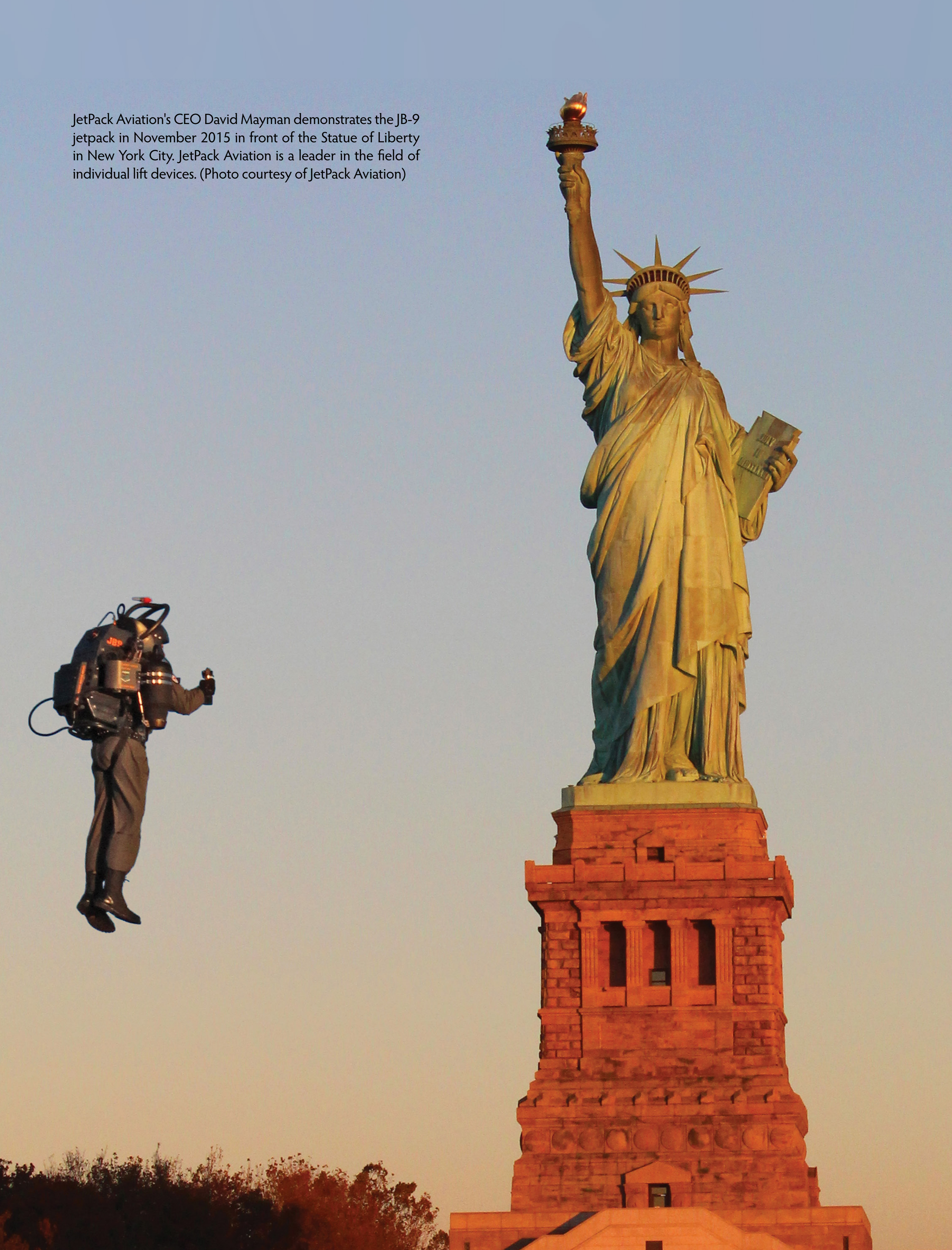
Undermining an adversary's A2/AD defenses. The USMC is developing the Expeditionary Advance Base Operations (EABO) concept as part of its efforts to defeat an adversary A2/AD system. The EABO concept aspires to breach an adversary's defenses yet minimize the vulnerability of concentrated forces.[27] The EABO employs "mobile, relatively low-cost capabilities in austere temporary locations forward as integral elements of fleet operations."[28] The realistically anticipated characteristics of ILDs are not only suitable for this approach, but they are also near synonymous. ILDs are highly mobile,

Chris Malloy, founder of Malloy Aeronautics, performs an initial tethered flight test of the original Hoverbike concept in December 2010 in Sydney. The hoverbike can lift up to three hundred pounds and fly at the same speed and height as a typical light helicopter but also operate close to the ground and around people. (Photo courtesy of Malloy Aeronautics)

whether defined as their ability to deploy to an advance base or be employed from one. They are exceptionally low cost in comparison to existing ground and air movement systems. Finally, their ability to operate without an extensive maintenance and supply infrastructure ensures their suitability for working in austere environments. These characteristics should attract military planners to the benefits of IL technology.

Augmenting autonomous systems. IL technology advancements also demonstrate the potential for ILD to augment autonomous systems. Autonomous systems such as drones, pilotless aircraft, and robotic ground clearance devices risk materiel rather than personnel. Instead of artillery or aviation bombardment, an offensive maneuver in future warfare may commence with a massed attack of armed drones employing swarm tactics. Inherently dangerous tasks such as mine clearance operations may well be conducted using mechatronic devices, and routine functions such as route control may be performed by artificially intelligent robots.

Regardless of the advancement of drone and autonomous system technology, the human factor of warfare will remain. Therefore humans, or more accurately soldiers, will still need to maneuver in the operational environment in the successful conduct of warfare. A combination of human performance combined with the advantages of autonomous or robotic systems, known as manned-unmanned teaming, offers unprecedented opportunities for more effectively conducting operations. ILDs can be integrated using this manned-unmanned teaming concept alongside drones or ground clearance robotics. At their broadest, ILDs could be employed as a redundancy option in case of major system or infrastructure collapse. As an example, a small team of operators using ILDs could maneuver with a reduced chance of detection and faster than rotary-wing aircraft, establishing a local network less susceptible to enemy interdiction than remote systems, and control fires from external platforms or a standalone system such as tactical loitering air munitions.



JetPack Aviation's CEO David Mayman demonstrates the JB-9 jetpack in November 2015 in front of the Statue of Liberty in New York City. JetPack Aviation is a leader in the field of individual lift devices. (Photo courtesy of JetPack Aviation)

Enhancing the ability to defeat adversaries in complex terrain. A global trend toward concentrating of populations in urban areas and in littoral regions together with the emergence of megacities presents the final area to be explored for the generic military application of IL technology. ILDs could prove vital in assisting militaries to negotiate complex urban and littoral terrain. For example, they might be employed by a maneuver force to rapidly isolate an objective. The anticipated size of ILDs would enable them to operate in areas of urban clutter too narrow and confined for rotary-wing aircraft or to achieve simultaneous landings in areas unsuitable for larger craft landing zones. Additionally, the expected maneuverability of ILDs would enable horizontal and vertical envelopment inside the urban terrain, maneuvering above and around infrastructure such as high-rise buildings. ILDs might also provide an individual medical evacuation capability that exceeds the reach and speed of other air and ground assets. Similar benefits apply in littoral regions. In addition, ILDs are unrestricted by ground obstacles such as marshlands, tidal variance, and inadequate or absent port facilities. ILDs' ability to rapidly insert and extract is a significant advantage that developers are promoting among other benefits.

Commercial Advances in Individual Lift Devices

Examining employment of ILDs from a commercial perspective can further illuminate the possibilities as well as challenges of incorporating ILDs in warfare. Of the multitude of companies introduced earlier in this article, the Malloy Aeronautics JTARV is a prominent example of advancements in IL technology. Its developers strike a balance between optimism and realism that was not evident in the claims of some earlier-generation developers. Greg Thompson and Mark Butkiewicz from Survice Engineering, a U.S.-based Department of Defense engineering firm and partner with Malloy Aeronautics, identify the JTARV as a complementary asset to existing military capability that increases options for the last leg of the logistics chain. It is not intended to replace the airplane, helicopter, or truck; it provides rather an alternative for "the last mile." Consequently, integration with existing systems to ensure the control of large drones amid other manned and unmanned aircraft is an important issue for current airspace deconfliction that will only increase. While the developers do not foresee technical hurdles to achieving manned flight using the JTARV, they are realistic about the challenges that a transition to an ILD would encounter and thus have been focused on unmanned uses of the platform.[29]

Thompson and Butkiewicz identify two primary constraints to the employment of ILDs: safety and conceptual aversion. The fundamental issue is safety. Fixed-wing aircraft can glide, rotary-wing aircraft can auto-rotate, both allowing an element of survivability during an emergency or crash landing. Anticipating emergency survivability measures, parachutes were included in the WASP II project. However, this was considered an emergency precaution rather than an inherent redundancy measure. Future ILD platforms will likely need a level of emergency measure redundancy to be approved for manned flight.

The second issue is conceptual aversion, primarily by political and military decision-makers. This aversion likely results from the safety and survivability issues already identified, magnified by a credibility gap generated by decades of failed promises rather than proven capabilities. Thompson recognized that, while technology can quickly be developed, implementation will likely be gradual, and the more significant challenge will be a "paradigm shift to overcome inertia."[30]

The chief executive officer of JPA, David Mayman, has demonstrated a cautious and pragmatic optimism regarding the potential for ILDs. His restrained enthusiasm, however, contrasts with the leading-edge progress of JPA jetpacks. As introduced earlier, this company has developed and tested individual lift devices that "fly faster than any helicopter and produce a lower heat signature," and have passed the Federal Aviation Administration certification requirements.[31] The JPA Jetpack, JumpJet, and load-carrying SHRPA models all have multiple redundancy features. These include the ability to maintain flight with one or more motors inoperable and redundant wiring and control signals, thus countering an enduring criticism of ILD safety. Mayman notes that military developers desire ballistic protection, noise reduction, and the possibility of weaponizing ILDs. These are significant aspirations for a capability that has been dismissed for decades.[32]

Examining Strengths, Weaknesses, Opportunities, and Threats

Having provided an overview of some generic military applications for IL technology, it is useful to explore the implications of military employment of ILD using the "SWOT" market analysis framework. SWOT is a strategic business planning tool that examines the strengths, weaknesses, opportunities, and threats to a business or a market. It originates with a Stanford University research project that aimed to identify reasons for corporate failure.[33] Strengths and weaknesses are the positive and negative components that can be controlled or influenced. Opportunities and threats are the positive and negative components that cannot be controlled.

Individual lift device strengths. According to the SWOT framework, primary strengths of IL technology are its flexibility, low signature, and relatively low cost compared to existing aviation platforms. There are many factors that contribute to the flexibility of ILDs. More importantly, ILDs multiply maneuver options by the lowest divisible level: the individual. Additionally, the small size of many ILDs creates force deployment opportunities not feasible with other platforms. ILDs can be bulk transported by air, sea, and ground routes, or self-deploy in autonomous or manned modes. Small ILDs can be retained, air-dropped, or self-deployed as personal extraction devices. They can also be incorporated into protected mobility platforms, either as an aid to maneuver or as an extraction method comparable to a pilot's ejection platform.

ILDs can be used in foreign humanitarian assistance and disaster relief operations, either alone or in conjunction with unmanned logistics platforms. They can be employed from sea-based platforms as part of amphibious operations, from the ground, or, with further development, launched from airborne platforms as a controllable and maneuverable capability. And, the ability to rapidly maneuver and bypass obstacles make ILDs highly suitable for gap crossing operations, either as part of a security force or as the primary method for crossing gaps and obstacles. ILDs also have the advantage of small detection signatures.

The *Marine Corps Operating Concept* identifies the "battle of signatures" as one of five key drivers of change in the future operating environment of 2015–2025.[34] The signature of ILDs seems to fit the Marine Corps stipulation. There is no requirement for ILDs operating by a pilot control to emit electronic signals, they present a small heat signature, and manned platforms can be masked within a fleet of unmanned systems. Additionally, ILD operators can employ terrain masking tactics or disperse in complex terrain to avoid detection. As a result, they are less vulnerable to detection than existing major platforms and therefore create an advantage for militaries that adopt them as part of their capability mix.

ILDs appear to be a significantly more cost-effective capability than existing methods of aerial insertion and extraction. A 2011 proposal by Lt. Col. James Hammett of the Australian Army highlighted the starkness of this cost comparison: the price of one multirole helicopter equated to approximately five hundred Martin Aircraft Jetpacks.[35] This cost comparison would be starker once sustainment and training costs are included in the comparison. The WASP II prototypes developed by the U.S. STARS-V program relied on kinesthetic controls and required skill and extensive pilot training. By contrast, it is relatively inexpensive to teach a soldier to operate a modern ILD. For example, JPA recently trained USSOCOM members to operate their Jetpacks within a week, and one of their models can be operated with even less training.[36] Advances in simulated training will only reduce the costs of money and time. However, a purely numerical analysis does not account for the intangible benefits of rotary-wing aviation, and the most significant of these is reduced risk.

Airworthiness standards have lowered the risk to personnel but also restricted the flexibility of rotary-wing aviation. The often exorbitant and rising cost of air mobility platforms reduces the willingness of commanders to employ these high-value assets in a contested operational environment. Casualty evacuation is an example. The decision to employ casualty evacuation aircraft requires analysis of the risk to aircraft, aircrew, and medical personnel, all three of which are finite and expensive military assets. Casualty evacuation and movement of medical personnel by ILD reduces the risk equation and can enhance casualty evacuation rates. In short, ILDs enhanced with sufficient redundancy measures and protection are risk-worthy and can, therefore, be employed on the battlefield of the future.

Individual lift device weaknesses. That said, ILDs have weaknesses that must be mitigated. Flexible employment options and reduced signature incur a cost, but in the case of ILDs, that cost does not appear to be financial. The primary weaknesses of ILDs are reduced force protection, airspace deconfliction, and technical limitations of ILD such as noise levels. Despite the progress of IL technology, these weaknesses are significant and must be mitigated or accepted as risk. The most notable of these risks is force protection. Notably, a decision to adopt ILD could be perceived as contrary to the protected mobility approach. Protected mobility is the safeguarding of personnel en route to and on the battlefield. Commanders accept degraded situational awareness, route limitations, and the concentration of forces to reduce their forces' exposure to the physical dangers of battle. The lift capacity of current ILDs precludes the fitment of armor and other protection that is afforded to rotary-wing aircraft. As a result, ILDs are vulnerable to direct fire. This weakness may be mitigated but is unlikely to be overcome in the near term.

The cover of *Science and Mechanics*, March 1963 edition. (Photo courtesy of Davis Publications)

Yet force protection is more than the ability to withstand direct fire. In fact, a more effective approach to force protection would be to avoid detection where possible. It is in this area that ILD can mitigate their vulnerabilities. Forces inserted via ILD are smaller and less detectable; they are therefore harder to identify, track, and target. Also, ILDs can operate at altitudes beyond the accurate range of small-arms fire and yet able to maneuver in complex terrain, limiting the effectiveness of air-to-air weapons. Despite efforts to mitigate these risks, any ILD concept for employment will be challenged by force protection requirements and the associated trend toward autonomous technology. Although this trend is pervasive, the possibility of a battlefield devoid of humans within the next fifteen years is unlikely.

Another weakness of ILDs is airspace deconfliction. Airspace deconfliction is the coordination of aviation platforms with each other and with above-surface fires. The employment of ILDs will add to the challenges that the proliferation of manned and unmanned aircraft and the increased range of surface-generated fires has already created. Adding ILDs to the airspace will add challenges that are not currently present in the coordination of unmanned aircraft and ground-based fires. While it is true that a soldier or a marine can be trained to operate one of the current model ILDs within a week, it is unrealistic to expect the same competency in airspace awareness of a rated pilot, regardless of additional training time. Methods of airspace coordination must, therefore, be designed to meet this shortfall.

Technical methods may work to mitigate the problem. For example, ILDs could be limited to below a predetermined coordinating altitude or prevented from entering a restricted zone. An alternative method is the integration of a tracking system to control fires away from an ILD force. But, despite mitigation efforts and regardless of whether IL technology is realized, the problem of airspace deconfliction will remain a challenge for the future operational environment.

JetPack Aviation JB-10 jetpack during takeoff February 2017 in Southern California. This jetpack—a backpack style with two turbine engines on either side—has the ability to elevate up to one thousand feet per minute with an endurance level clocked at around five to ten minutes depending on the fuel levels. (Photo courtesy of JetPack Aviation)

Another continuing challenge for IL technology is noise, particularly in turbine-powered ILDs. For example, the Martin Industries Jetpack produces ninety decibels at full throttle.[37] Noise, therefore, becomes a force protection issue for operators and other personnel, including noncombatants, and may limit the flexibility of ILDs in some noncombat roles such as foreign humanitarian assistance/disaster relief. Thus, noise attenuation must be a priority for ILD developers. If further noise reduction is unachievable then noise must be countered, mitigated, or used to advantage. This includes the masking of sound by terrain or route selection, or by the use of noise to induce fear in an adversary. Having considered the weaknesses of IL technology, it is only appropriate to analyze the opportunities.

Individual lift device opportunities. The primary opportunities for ILDs are advances in alternative power technology and integration with surface and subsurface individual mobility platforms. Thrust, or more accurately the ratio between thrust and weight, is the most significant factor in developing IL technology. The examples outlined in this article have each advanced a particular method of power generation such as a turbojet or a turbofan. Some of these efforts have been industry leaders, for example, the Martin Aircraft motor that generates more efficient thrust than the Joint Strike Fighter.[38] Global improvements in battery storage and weight reduction have also created opportunities for electric-powered ILDs. Additionally, engine refinements have increased the lift capacity, flight duration, fuel efficiency, and more importantly, safety of flight. Further advancements will only increase this evolution. An example of this is the MyT (Massive Yet Tiny) engine, a nonreciprocating internal combustion engine that claims significantly higher power to weight output than conventional motors. The MyT offers an additional advantage in its suitability as a single-engine type for a variety of mobility platforms.[39] This level of integration leads to the second opportunity, that of integration with other surface or subsurface mobility platforms.

The opportunities for ILD cannot be considered in isolation. Instead, they should be considered as part of a broader approach to mobility. Current military mobility platforms are mainly restricted to a singular domain. Planes fly in the air, armored vehicles maneuver on land, and naval vessels navigate the world's waters. The USMC Landing Craft Air Cushion is an example of technology that has breached these barriers. The USMC MV-22 Osprey also extends the marines operational reach by combining the benefits of vertical lift and forward propulsion. Pioneering individual mobility solutions are not as revolutionary; however, Gibbs Sports Amphibians manufacture an exemplar product that could be employed to enable personal mobility on sea and land. The Quadski is a single platform with speeds capable of 45 mph on water and land.[40] An opportunity exists for ILD developers to integrate platforms that enable maneuver between and within these domains and therefore create a competitive advantage over adversaries. An example is the combination of the aerial insertion capability of an ILD with the ground maneuver capability of a tracked Segway-type vehicle.[41] A more ambitious aim would be the integration of exoskeletons.

Development of an exoskeleton with integrated lift capacity would revolutionize individual mobility on the battlefield. An exoskeleton is a physical structure that protects and enhances the capabilities of the soldier or marine. An exoskeleton could either contain IL technology or be capable or integrating with an ILD. By maintaining a separate, yet integrated ILD, the operator could maneuver on the surface and employ the ILD as organic aerial observation, fire support, and lift capability. Technology to realize this capability, including artificial intelligence, autonomous flight control, and as outlined, power generation technology, is progressing independently. For the last component, it is realistic to assume that advancements in power generation will increase the lift capacity of existing ILDs to a stage where they are capable of lifting an exoskeleton. Current developments in turbine technology with the potential to lift seven hundred pounds advances this science-fiction image toward reality.[42] Such improvements would not only be the realization of individual mobility but also of protected and enhanced individual mobility.

Threats to individual lift devices. Though the opportunities for military use of ILDs are momentous, the threats to military adoption of IL technology are significant and enduring. Threats to military adoption of IL technology include organizational and societal risk tolerance and the impact of adversary development of counter-ILD technology. Of these, the acceptance of risk is the most important. National and military leaders employ their limited military capabilities judiciously, and of these limited capabilities, it is the human resource that is the most valuable. Therefore, it would be unrealistic and unwise to expect leaders to employ their scarce resource in untested or high-risk technology; like the airplane before World War I.

The threat to military adoption of ILD is the entrenched political and military aversion to risking personnel as opposed to materiel. Consequently restricted by the paradigm of requiring protected mobility together with memories of IL technology failures in the past impede a fair assessment of ILD potential. If ILDs remain limited to private and commercial use, developers have little incentive to develop counter-technologies aside from meeting regulatory and public security requirements. The only credible counteraction to this threat is the impartial demonstration and testing of ILD capability and potential, in which defense scientific organizations must play a crucial role. Defense scientists are well placed to test the claims of ILD developers and promote the significant industry achievements that have occurred since the days of dangerous and ineffective hydrogen peroxide jet belts.

An adversary's development of counter-ILD technology also poses a credible threat that may arise out of counter-drone or antiaircraft technology. Examples of counter-ILD technologies include directed-energy and direct-fire weapons, more sophisticated landing area denial measures, and electronic attack. Militaries that adopt ILDs must therefore concurrently develop methods to counter adversarial capabilities.

Keeping Up to Prevent Catching Up

As with other technology, the benefit of early adoption is often associated with an enduring competitive advantage. Global developers have advanced IL technology because the commercial potential is apparent. For example, Dubai's plans for emergency and passenger transport using "hoverbikes" and autonomous aviation platforms are enabled by Russian commercial developers. Additionally, the revolutionary achievements of New Zealand-based Martin Industries are now being jointly developed with a Chinese organization. Ominously, military competitors to the United States and its allies are pursuing these technologies including the development of a Russian "hoverbike."

The U.S. Army Research Laboratory's support for the Malloy Aeronautics JTARV and the USSOCOM agreements with JPA are positive steps toward recognizing the potential for ILDs, but the tempo and scope of these projects must be expanded if these technologies are to be fully realized.

The USMC STAMP program is a model for military planners and defense scientists to emulate. The Marines established a vision for military ILDs, engaged and funded a leading commercial firm to develop a prototype, and engaged with other services for collaborative research. The difference for today's IL champion is that the technology now matches the vision and the only way is up.

Conclusion

Significant advances in IL technology present an opportunity to integrate ILDs into future military capability. ILDs have the potential to enhance a military force's ability to conduct distributed maneuver, undermine adversary A2/AD defenses, augment autonomous systems, and defeat adversaries in complex terrain. These are significant potential benefits that must be considered impartially as military priorities are evaluated. With regard to the development of ILD, organizational barriers related to risk tolerance also must be overcome by reframing the potential of ILDs. The potential benefits resulting from ILD strengths and opportunities are sufficient to warrant further examination of their military potential and investment in their development. ■

Notes

1. Steve Lehto, *The Great American Jet Pack: The Quest for the Ultimate Individual Lift Device* (Chicago: Chicago Review Press, 2013), 176.

2. Ibid., 3, 156–63.

3. Bernard Lindenbaum, *V/STOL Concepts and Developed Aircraft: Vol. I, A Historical Report (1940-1986)* (Fort Belvoir, VA: Defense Technical Information Center, 1986), 2-1, accessed 12 July 2018, http://www.dtic.mil/dtic/tr/fulltext/u2/a175379.pdf.

4. Ibid., 2-12–2-28.

5. Lehto, *The Great American Jet Pack*, 75–92.

6. Lindenbaum, *V/STOL Concepts and Developed Aircraft*, 2-46–2-61. Although the noise of the Sud *Ludion* was considerable, it was significantly less than the Bell model concurrently under development.

7. Ibid., 3-31–3-38. The U.S. Marines' (USMC) concept for employment indicated it should fly "among the tree trunks, beneath the forest canopy, taking advantage of the cover and concealment afforded by the natural environment—actually pushing aside or penetrating frangible vegetation, landing and taking off in spaces too small to accommodate a helicopter even the in the absence of barriers to access." The USMC Small Tactical Air Mobility Platform (STAMP) program operated on a shoestring budget, allocated only $2.18 million from 1970–74 to design, develop, and deliver a tested prototype. Its notable difference from the subsequent U.S. Army Small Tactical Aerial Reconnaissance System-Visual (STARS-V) program was that it was required to lift two people.

8. Ibid., 3-14–3-30.

9. Ibid., 3-38.

10. Ibid., 3-38–3-40.

11. Ibid. The U.S. Army leveraged the Williams Aerial Systems Platform (WASP) research already conducted by Williams International under the STAMP program to conduct the STARS-V program with an equally small $2.54 million budget. The Army program requirement under STARS-V was articulated as "We

are not looking for a weapons carrier or a load carrying device. We are simply looking for a one-man conveyance, without rotor blades, which can move safely in constricted spaces, can communicate by means of FM radio and can be operated by essentially untrained or quickly trained, run-of-the-mill, unit personnel. If it requires a certified pilot or long training, we are not interested. We would see company executive officers, Battalion S-3, Battalion and Brigade Liaison Officers using these devices for coordination, liaison, battle position reconnaissance and troop leading."

12. Ibid., 3-39–3-58.

13. Ibid., 3-101–3-114.

14. Mark Prigg, "US Soldiers Could Soon Travel like Stormtroopers: Military Bosses Developing Star Wars 'Hoverbikes' for the Battlefield," *Daily Mail* (website), last modified 15 June 2015, accessed 8 June 2018, http://www.dailymail.co.uk/sciencetech/article-3125412/US-soldiers-soon-travel-like-storm-troopers-Military-bosses-developing-Star-Wars-hoverbikes-soldiers.html.

15. "Buzzcraft," *Army AL&T Magazine*, October-December 2015, 203–4.

16. Greg Thompson and Mark Butkiewicz (senior management, Survice Engineering), telephone interview by author, 3 October 2017.

17. Douglas Ernst, "Army 'Hoverbike' Prototype with 300-Pound Payload Capacity Passes Key Test," *The Washington Times* (website), 18 January 2017, accessed 8 June 2018, http://www.washingtontimes.com/news/2017/jan/18/army-hoverbike-prototype-with-300-pound-payload-ca/.

18. David McNally, "Army Flies 'Hoverbike' Prototype," U.S. Army, 17 January 2017, accessed 8 June 2018, https://www.army.mil/article/180682.

19. "Specialists," Martin Jetpack, accessed 8 June 2018, http://www.martinjetpack.com/sales/manned-jetpack0.html. The flight time is limited by Federal Aviation Authority fuel capacity regulations.

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21. "Dubai Police Announce Electric Star Wars-style Hoverbikes for Officers at Gitex Tech Conference," Australian Broadcasting Corporation, 14 October 2017, accessed 8 June 2018, http://mobile.abc.net.au/news/2017-10-14/dubai-police-announce-star-wars-style-hoverbikes-for-officers/9049860?pfmredir=sm. "The Hoversurf Scorpion … Russian-made craft can fly at a height of five meters and carry a police officer over congested traffic in emergency situations … 'The bike can also fly without a passenger and can go up to six kilometers ….' 'It can fly for 25 minutes and can carry up to 300kg of weight at a speed of 70kph.'"

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23. "How It Works," GoFly Competition, accessed 8 June 2018, http://goflyprize.com/how-it-works/. "VTOL" is vertical take-off and landing, a capability employed by rotary-wing and some fixed-wing aviation platforms.

24. David Mayman (chief executive officer, JetPack Aviation), interview by author, 11 December 2017; JetPack Aviation, accessed 8 June 2018, http://www.jetpackaviation.com/military/.

25. U.S. Marine Corps, *Marine Corps Operating Concept* (Washington, DC: Department of the Navy, September 2016), 16.

26. James Hammett (colonel, Australian Army), interview by author, 3 November 2017; Lt. Col. James Hammett, "Starship Troopers – A Reality?" (unpublished manuscript, 2012), Microsoft Word file.

27. Matthew Clapperton, "USMC Outlines 'Inside Force' Concept," Jane's 360, 26 October 2017, accessed 8 June 2018, http://www.janes.com/article/75228/usmc-outlines-inside-force-concept (subscription required).

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