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HYPERSONIC FLIGHT:

TIME TO GO OPERATIONAL

by

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Biography

Lieutenant Colonel Robert A. Dietrick is a US Air Force acquisition manager assigned to the Air War College, Air University, Maxwell AFB, AL. He graduated from the University of Dayton in 1990 with a Bachelor of Mechanical Engineering and again in 1992 with a Master of Science in Mechanical Engineering. He has held a number of engineering and program management positions for multiple programs in various stages of the acquisition cycle. In addition, he has served at both HQ AFMC and on the Air Staff. Prior to attending Air War College, he served as the Assignments Branch Chief at the Air Force Personnel Center for five acquisition related career field totaling 8,500 personnel.

Abstract

Anti-Access and Area Denial threats are increasing and could jeopardize the ability of the US Air Force to effectively conduct global strike by 2032. Scramjet powered hypersonic flight could be a key capability by reducing time to strike and increasing survivability. Historically, the key challenges preventing hypersonic flight have been in the areas of propulsion, heat, plasma interference, and weapons employment. This paper examines the current status of these challenges and the potential to solve them for a hypersonic cruise missile application. In particular, the success of the X-43A and X-51A scramjet demonstrations are considered as establishing the foundation for a hypersonic cruise missile. While current technical maturity supports a cruise missile application, a hypersonic bomber would still be a high risk proposition and likely would be more expensive than a standoff bomber and hypersonic cruise missile combination. Recommendations include sustained research and development funding for hypersonic technology, a hypersonic cruise missile technical development program in support of a hypersonic cruise missile acquisition program, and sustained procurement of the missile to ensure a sufficient inventory is maintained.

Introduction

The year is 2032. Globalization largely came to an end several years ago amid international economic chaos resulting from bitter trade disputes fueled by trade and currency imbalances. The United States, Europe, China, and Russia are the dominant economic and political powers and have successfully built independent trade networks with "satellite states" that overwhelmingly favor the mother state. India and Brazil are racing to join the elite club and the competition for resources is global and increasingly fierce. The United States maintains a substantial traditional military superiority but is increasingly challenged by Anti-Access/Area Denial (A2/AD) weapons deployed to threaten aircraft, airbases, and naval assets, especially aircraft carrier battle groups.

The future is uncertain and the preceding vision of the future is just one of many possibilities. Regardless of what form the future takes, however, several things can be known with reasonable certainty. Prompt global strike—the ability to strike targets anywhere in the world within eight hours—will remain a valid mission requirement.[1] A2/AD systems will become increasingly capable as defensive systems are fielded more rapidly than aircraft systems. Fielded and soon to be fielded systems including the F-22A and F-35 fighters complimented with currently available standoff weapons will struggle in this environment. Each of these platforms has one or more deficiencies with respect to unrefueled range, speed, and/or stealth. Furthermore, they are all limited by the current inventory of subsonic cruise missiles. There is a pressing need for new systems with the ability to more rapidly strike targets of interest.

After six decades of exponential increases, the top speed of fighter aircraft reached a plateau in 1967 and has stagnated ever since. Figure 1 plots the top speed of fighter aircraft based on the first year of operational deployment. The exponential increase in top speed is clearly evident for piston driven and turbojet/turbofan driven aircraft both individually and combined with the latter taking over fighter propulsion in 1945-1948 and quickly maturing over the next twenty years. Since the late 1960s, however, top speeds have stagnated without a clear successor to the turbofan engine, but technological advance is on the verge of another breakout in sustained speed.

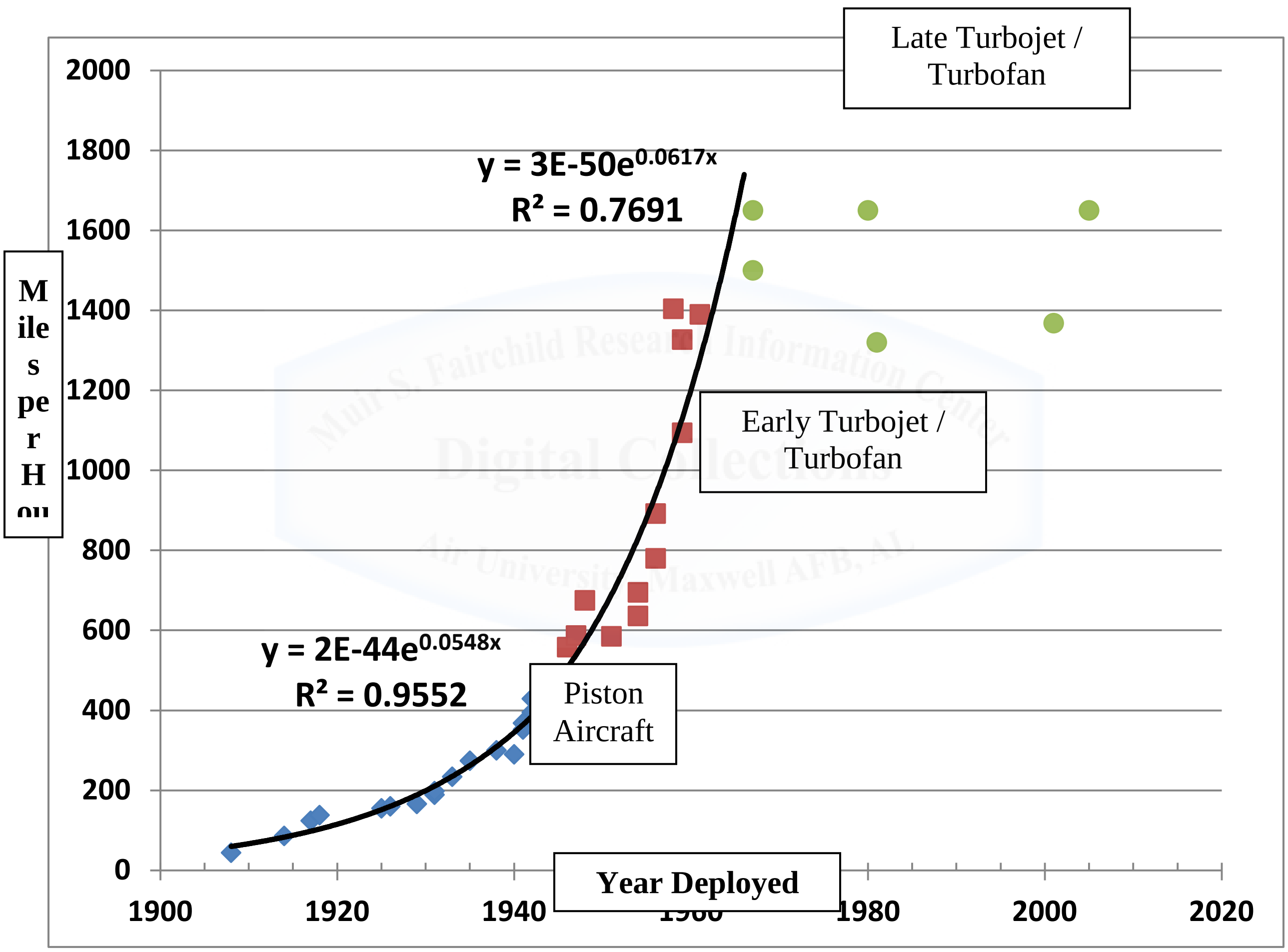

Figure 1. Top Speed of US Fighter Aircraft[2,3]

Sustained funding for hypersonic technology advanced development with the specific objective of acquiring and deploying an air-breathing hypersonic cruise missile (HCM) will ensure the continued capability of the USAF. The HCM will provide the key capability to counter future A2/AD challenges at an affordable cost. Several key technical challenges are in the final stages of being conquered, enabling an old dream to finally be realized. This paper begins by exploring hypersonic flight and its growing importance to counter future threats. Narrowing the scope to air-briefing hypersonic flight, it addresses the solutions to the major challenges of propulsion, extreme heat and thermal loads, and plasma effects. While current technical maturity supports a cruise missile application, a hypersonic bomber is still a high risk proposition and likely more expensive than a standoff bomber and hypersonic cruise missile combination. Recommendations include sustained research and development funding for hypersonic technology, a hypersonic cruise missile technical development program in support of a hypersonic cruise missile acquisition program, and sustained procurement of the missile to ensure a sufficient inventory is maintained.

Growing Importance of Hypersonic Flight

Several different methods exist to reach hypersonic flight. Hypersonic flight is generally defined as flight at speeds greater than Mach 5. The most mature method of reaching hypersonic speed employs ground-based rockets for either a ballistic or boost-glide flight with either an orbital or sub-orbital flight. The de-commissioned space shuttle and HTV-2 technology demonstrator are examples of this type of hypersonic flight reaching very high speeds of Mach 20+. The most ambitious method and uses air breathing propulsion and conventional take-off to reach hypersonic speeds and is frequently referred associated with Single Stage To Orbit (SSTO) concepts. The final method uses a rocket booster to accelerate a vehicle to around Mach 4+ and then an air breathing ramjet or scramjet engine engages to power the vehicle to hypersonic speeds. This method could employ the rocket booster in either a ground launch or air launch configuration and is the primary focus of this paper.

Hypersonic flight has a long history of being the technology of the future but is benefitting from renewed interest. After World War II, the United States supported a relatively robust portfolio of projects and programs to push the limits of manned flight. Multiple experimental planes such as the X-1, X-2, and X-3 were built to explore the science of aerodynamics and propulsion with no expectations of becoming operational. With the rocket-powered X-15, this investment portfolio entered the region of hypersonic flight, reaching top speeds of Mach 6.7.[4] Early attempts to develop operational hypersonic platforms were only tentatively supported, leading to their abandonment when initially optimistic schedules and cost estimates gave way to more harsh realities. In the near future, however, hypersonic flight has the potential to enable rapid global strike against the most modern Integrated Air Defense Systems (IADS) while maintaining compliance with strategic arms treaties and minimizing the impact on the current deterrence framework.

Future Threat to Stealth

The ability of stealth aircraft to penetrate adversary IADS might be significantly at risk by 2032. Forecasting future counter-stealth capabilities and mitigations to these counters is difficult. However, several publications suggest advances in aerial surveillance might undermine stealth in the future. Willis and Griffiths provide a detailed technical summary of advances in bi-static radar and the likely vulnerability of stealth to Very High Frequency (VHF) and Ultra High Frequency (UHF) radars due to the difficulties in absorbing these frequencies.[5] Westra highlights advances in computer processing capability and radar software that now make it feasible to detect small signature objects even in high clutter environments.[6] Westra concludes that "Basic stealth techniques…will be much less effective" and will "likely provide inadequate protection" against future IADS.[7] Letsinger expands on these threats with a summary of millimeter wave radar, Passive Coherent Location technology, and existing claims of being able to detect the B-2.[8] Despite these advances, Letsinger cautions that the potential for these capabilities to actually counter stealth is "controversial."[9] Nevertheless, it seems reasonable to conclude that in the future there might be windows of vulnerability when counter-stealth technology has the advantage and USAF stealth platforms are at significant risk.

Survivability Benefit of Hypersonics

Speed, altitude, and signature all have an impact on the survivability of aircraft and missiles. According to the National Research Council's Air Force Studies Board, increases in speed are more important to defeating some IADS threats than improvements in stealth.[10] Supporting this claim, separate studies concluded that the probability of survival can be substantially increased by achieving speeds in excess of Mach 6.[11] In particular, hypersonic missiles "would likely have a high probability of survival against air defense threats regardless of the signature level achieved."[12] In addition to the advantages of increased survivability, commanders could also accept higher survivability risks with a cruise missile than with a manned platform.

Shorter Kill Chain

Although further stealth improvements might also increase survivability, only higher speed can significantly reduce the time required to engage identified targets. There is considerable opportunity to reduce the flight time required for a cruise missile being employed at ranges exceeding 500 nautical miles. The current AGM-86C Conventional Air Launched Cruise Missile (CALCM),[13] and the Joint Air to Surface Standoff Missile-Extend Range (JASSM-ER) are both limited to "high subsonic" speeds.[14] Based on even optimistic estimates of "high subsonic" maximum speeds, these missiles would require over 55 minutes to strike targets at a range of 500 nm.[15] By comparison, a HCM travelling at Mach 6 would cover the same distance in only six minutes.[16] The compressed shooter-to-target kill chain would redefine "time-sensitive targets" and "actionable intelligence."[17] Such a weapon would provide combatant commanders with a significant capability increase by overcoming "the constraints of distance, time, and defense that currently limit conventional aerospace power projection."[18]

Treaty Compliance

Other rapid global strike alternatives exist but carry substantial political costs with respect to treaty compliance and strategic signaling. Using a conventional warhead with either an Intercontinental Ballistic Missile or a Submarine Launched Ballistic Missile is among the obvious global strike alternatives. However, programs to explore these alternatives generated concern in Congress during the FY2007 and FY2008 budget cycles resulting in only limited funding being appropriated for exploration of the Conventional Trident II Modification (CTM) program.[19] The primary issue of these alternatives is "nuclear ambiguity" in that it would be impossible for other states to differentiate between the conventional and nuclear versions of these weapons during the launch and much of the missile flight.[20] From a treaty perspective, the operational deployment of the conventional strike missile (CSM) would currently violate the Strategic Offensive Reduction Treaty (SORT), and the permissibility of the CTM deployment is questionable.[21] These deployment issues could be solved if the New START Treaty of 2010 is ratified, but this remains in doubt.[22]

Furthermore, even if the issue of deployment is resolved, a final issue of employment may remain. Currently, the employment of either of these systems would require a 24-hour notification of the event, to include the impact area, under the Ballistic Missile Launch Notification Agreement of 1988.[23] Although some have argued that "the nation's leaders have a solemn obligation to do whatever it takes to save American lives and protect our vital interest" and that these weapons should still be pursued,[24] this ignores the vital US interest of promoting the rule of law to include treaties and to avoiding the perception of being a rogue superpower. By deploying only a conventional version of a HCM, these heavy political costs can be avoided.

Solving the Challenges of Hypersonic Flight

With all of the potential benefits of hypersonic flight, it should be obvious that obstacles must exist otherwise hypersonic systems would be in regular operational use today. The specific challenges associated with a hypersonic system are partially dependent on the system concept and configuration, but the general challenges can be summarized as propulsion, heat and thermal loading, and possible plasma effects. For a HCM application, key technologies for these challenges appear to be reaching maturity.

Propulsion

There are several different types of relevant propulsion systems, including rocket engines and air-breathing engines with varying efficiencies. Currently, rockets engines are the primary propulsion systems for reaching hypersonic speeds, usually associated with space lift. But the major limitations of rocket engines are the need to carry both the fuel and oxidizer for the engine and the correspondingly short burn time for the engine.[25] This results in a relatively inefficient engine with a low specific impulse. The definition for specific impulse is the "net thrust generated per unit mass flow rate," which is represented as lbf-sec/lbm.[26] For the space shuttle main engine burning hydrogen and oxygen, the specific impulse is about 363 lbf-sec/lbm at sea level.[27]

On the air-breathing side, jet engines come in several different varieties including the turbofan, turbojet, ramjet, and supersonic combustion ramjet (scramjet). Turbofan and turbojet engines both include compressor stages to pull air into the engine prior to combustion. The turbofan is optimized for subsonic flight and the turbojet is optimized for lower supersonic flight. By contrast, pure ramjets and scramjets have no rotating machinery and instead rely on positive airflow for compression, meaning they produce zero thrust at zero speed, making them dependent on some other means to generate initial speed.[28] For a ramjet, the inlet configuration and diffuser slow the airflow to subsonic speeds prior to combustion resulting in an engine optimized for high supersonic speeds.[29] For hypersonic flight, the air-breathing solution is the scramjet. As the name implies, scramjet combustion is at supersonic speed, which optimizes the engine for hypersonic speed by reducing drag and avoiding the sharp air temperature increases into the engine associated with slowing the air to subsonic speeds.[30]

Air breathing jet engines are significantly more efficient than rocket engines because they only need to carry the fuel being burned instead of both the fuel and oxidizer of a rocket engine. As a result, some turbofan engines operating at subsonic speeds have a specific impulse of nearly 6,000 lbf-sec/lbm, over 16 times more efficient than the space shuttle main engine.[31] Hypersonic optimization and a higher specific impulse than rocket engines result in the scramjet having the highest future potential.

Realizing the potential of the scramjet has not been easy, but the technology is finally maturing. Since scramjets produce zero thrust at zero velocity, they rely on booster rockets or combination cycle engine for acceleration to hypersonic or near-hypersonic speeds prior to starting the scramjet. The booster rockets could be used in either a ground-launch or an air-launch configuration. The challenge is then igniting and maintaining combustion under extreme conditions, a “challenge often compared to trying to keep a match lit in a hurricane.”[32] Several experimental systems have made progress at conquering this challenge.

The X-43A (Hyper-X) was a NASA experimental project to demonstrate a small hydrogen-fueled scramjet on a platform similar in size to a cruise missile. The program consisted of three flights launched from a B-52B test aircraft, with the first test ending in failure due to stability control issues.[33] In its second flight in March 2004, the X-43A successfully tested the scramjet engine, producing positive thrust and reaching a top speed of Mach 6.83 during the ten second engine burn.[34] The third and final flight test of the X-43A in November 2004 reached a top speed of Mach 9.6 during the 11 seconds of scramjet-powered flight.[35] In terms of distance, the X-43A travelled 600 nm after separating from its rocket booster and a total of 840 nm from its launch point.[36]

Following the X-43A is the USAF X-51A Waverider program. Similar to the X-43A, the air launched X-51A is roughly the size of a Conventional Air Launched Cruise Missile (CALCM). According to Charlie Brink, the program manager, the program consists of four flight test vehicles with objective of demonstrating a hydrocarbon-fueled scramjet at Mach 5+. The scramjet is initially primed with ethylene and then transitions to JP-7. The first flight test in May 2010 successfully demonstrated continuous scramjet operation for about 143 seconds but only achieved Mach 4.9, probably as a result of a seal leak resulting in a loss of thrust.[37] Unfortunately, during the second flight test, the engine suffered an unstart during the transition from ethylene to JP-7 and could not be re-started.[38] The third flight in August 2012 was also unsuccessful due to a failure of one of the control surface actuator subsystems.[39] This leaves just the final fourth flight to demonstrate a long continuous scramjet burn with a Mach 6 speed goal.

Engine and Airframe Materials

One of the key challenges to hypersonic flight is overcoming the extreme thermal loads associated with those speeds. Although Mach 5 is often used as the definition for hypersonic flight, a more precise definition is the speed at which air no longer flows around the vehicle but instead stagnates at the leading edges, roughly at Mach 5.4.[40] This stagnation generates very high pressures and thermal loading on the aircraft. Critics of hypersonic flight note that these effects combined with mechanical and acoustic loads and engine combustion can produce temperatures in excess of 2,800°C.[41] Although the potential for high temperatures garners most of the attention, there are multiple aspects of the thermal problem. The duration of flight and the amount of heat required to raise the temperature of the structure are also critical variables. Douglas Aircraft recognized these factors in their near-winning 1955 proposal for the X-15 program,[42] recommending a thicker-skinned but lighter weight airframe using a thorium-zirconium alloy of magnesium that would experience lower overall temperatures due to its superior ability to absorb thermal loads.[43] In the end, North American won the contract with a more conventional airframe design using a nickel-based Inconel alloy for the skins.[44]

Even fifty years later, the extreme thermal loads still present a significant challenge for material selection. According to a recent hypersonic structural analysis, cost effective candidate materials for this application include various titanium alloys, nickel-based alloys such as Inconel, and cobalt-based alloys such as the Haynes family of materials.[45] Carbon fiber reinforced Ceramic Matrix Composite materials were also initially considered but were subsequently rejected "due to high development and manufacturing costs."[46] In this case, a titanium alloy in various sheet and honeycomb formulations was selected for the outer skin to withstand hundreds of hours of repeated exposure to Mach 5.2 speeds in increments of about 30 minutes.[47]

Although a difficult problem, providing an adequate solution for a HCM is much easier than for a reusable aircraft or spacecraft. As previously mentioned, the thermal load problem is a function of the duration of high speed exposure and the number of cumulative exposures. For a cruise missile, the total cumulative exposure to M5+ speeds is likely to be less than 18 minutes based on a Mach 6 missile with a 1,000 nm range.[48] This enables the X-51A to minimize the use of high cost exotic materials, leading to a cruiser body and rocket booster fins of conventional aluminum alloy, engine and cruiser fins of Inconel, an interstage flow-through of titanium alloy, a tungsten nose-cap, and a rocket booster with a steel skin and nozzle.[49] Additionally, spray-on silica-based ablative coatings are used on the cruiser body and Boeing Reusable Insulation 16 (BRI-16) tiles, same as those used for the space shuttle, are used for a small ventral section forward of the engine inlet.[50] The engine and airframe materials problem appears to be solved within reasonable cost for shorter duration hypersonic flights associated with a cruise missile application.

Terminal Guidance

Some concern has been expressed for the impact of plasma effects at hypersonic speeds on communications, to include the ability to receive GPS signals. The heat generated by a vehicle travelling through the atmosphere at high velocities causes ionization of the oxygen and nitrogen molecules, which can affect the propagation of electromagnetic waves.[51] However, scientific studies of this problem suggest that communications should not be affected below about Mach 16.[52] To date, flight tests of the X-43A at Mach 6.8 and Mach 9.6 have demonstrated no communications issues.[53] Based on this, there do not appear to be any unique issues with using GPS guidance for a HCM.

Other Considerations

Despite the potential merit of a HCM, there are a few major criticisms or counterarguments to be addressed. Generally, these counterarguments focus on either the preference for high capability platforms employing low cost munitions or the inherent risk and cost associated with developing and procuring HCMs. Some advocates of hypersonic flight favor a hypersonic, penetrating bomber as an alternative to a HCM. On the other hand, critics of hypersonic flight are unconvinced by the progress of the technology to date and do not believe developing a HCM is currently feasible.

Relative to feasibility, the recommendation of this research is to follow the X-51A scramjet demonstration program with a HCM demonstration program. The X-51A test program has one partial success and two failures, although one was clearly unrelated to scramjet technology" The fourth flight test, scheduled for 2013, will be a key event in assessing the maturity of several HCM key technologies. But even if the final flight test is an unqualified success, the dominant focus is still on proving the scramjet technology for a cruise missile type of application. The goal of a follow-on technology development program would be to demonstrate the maturity of other key technologies in a multi-vehicle test program to reduce technology risk and cost and schedule uncertainty. If successful, this HCM technology development program would silence questions of feasibility and support the progression to an acquisition program.

Why not a Hypersonic Bomber?

The recent progress in hypersonic research combined with the need for a new Long Range Strike system has generated interest in the acquisition of a hypersonic bomber. However, such an undertaking at the present time would be another rush to failure. To date, air-breathing hypersonic flight has been limited to a handful of successful flights using both air launches and sounding rockets. The longest flight test scramjet operation is less than three minutes in length, the longest flight covered less than 900 nm, and all have been conducted within a very narrow range of flight parameters. Perhaps most significantly, all of the scramjet flights have been conducted with single-use engines and airframes. The effort required to scale up engines and build air vehicles capable of flying just hundreds of missions for perhaps 60-90 minutes per mission would be immense and difficult to predict. A hypersonic aircraft would also introduce the problem of weapons employment, introducing issues that have not been addressed in any test program to date. What would be the effect of carrying external weapons at hypersonic speeds? What would be the impact of opening weapons doors at hypersonic speeds? Alternatively, decelerating to lower supersonic speeds for weapons employment and then trying to resume hypersonic flight would introduce additional propulsion challenges as the scramjets alone would be unable to accelerate from less than Mach 2 back to Mach 5+. Given these technical challenges, it seems reasonable to conclude that attempting to jump from current technical maturity to a hypersonic bomber would run a high risk of ending in cancellation as did the X-30 National Aerospace Plane, X-20 Dyna-Soar, and XB-70 programs.

Acquisition Affordability

Even if the technical problems could be solved, a HCM is still vastly more affordable than a hypersonic aircraft. The expected program acquisition cost including development and procurement for a HCM should be only a fraction of the cost for an aircraft. Table 1 shows relative cost comparisons between cruise missile programs and relevant aircraft programs. Approximate development costs can be obtained by subtracting the product of the quantity procured and the average procurement unit cost. This leads to cruise missile development costs decreasing over time from about $7B for the Air Launched Cruise Missile to about $4B for the

Advanced Cruise Missile to only $1B for the Joint Air to Surface Standoff Missile. This is in marked contrast to the significantly escalating development costs of advanced aircraft. The increased costs of the B-1B and B-2 in comparison to the B-52 can be attributed in part to the reduced radar cross section of both platforms and the supersonic maximum speed of the B-1B. Stealth characteristics, top speed, and increased system complexity are some of the key cost drivers in aircraft programs.

By minimizing these cost drivers for a large aircraft, it would be possible to acquire both a new bomber and a large HCM inventory. A cost study of various advanced bomber options estimated a $45B life cycle cost difference between a subsonic bomber and a Mach 7 bomber based on a quantity of 60 aircraft.[54] This cost difference would be more than adequate to fund the acquisition of a large number of HCMs. For example, if the HCM development cost was $10B and the unit cost $5M, then the Air Force could acquire 60 subsonic bombers and 7,000 HCMs for the cost of 60 hypersonic bombers.

Table 1. Comparison of Program Acquisition Cost and Average Procurement Unit Cost for aircraft and cruise missiles in BY2010 dollars.[55]

System	Program Acquisition Cost ($M)	Quantity Procured	Average Procurement Unit Cost ($M)
ALCM[56,57]	10,176.2	1,715	~1.85
ACM[58,59]	7,847.4	460	~8.18
JASSM[60]	3,589.4	2,487	1.04
B-52H[61]	~7,926.8	102	69.64
B-1B[62,63]	48,131.8	100	369.20
B-2[64,65]	69,880.0	20	1,508.90
F-22A[66]	77,799.9	187	208.02
Long Range Strike-B[67] (Estimate)	Unknown	100	550.00

Operations and Support Considerations

The combination of a less expensive, subsonic, standoff bomber and a large inventory of HCMs would reduce operations and support costs while increasing flexibility. A hypersonic aircraft would require special coatings and materials to survive the repeated exposure to substantial heat and high temperatures.[68] These coatings and materials would almost certainly increase the required maintenance and cost per flight hour. For example, the B-2 with its radar absorbent materials has a cost per flight hour of $135K compared to $72K for the B-52H and $63K for the B-1B.[69] As a one-time use asset, the HCM minimizes the hypersonic multiple-flight cost premium and is potentially even less expensive to maintain than a subsonic cruise missile based on fewer moving parts.[70] By relying on the penetrating capability of the HCM instead of the platform, a subsonic standoff bomber can achieve much lower operations and support costs.

The combination of lower cost platforms with higher capability munitions also provides greater operational flexibility. During peace, the USAF benefits from the lower operating cost of the subsonic bomber. If required to provide supporting fires in permissive environments such as Afghanistan, the subsonic bomber employing lower cost munitions will minimize per mission costs. If confronted with a more challenging threat environment, the same standoff platform can be mated with HCMs to either directly attack strategic targets or degrade adversary air defenses. This advantage can be further exploited by the potential to use contingency funding to replace HCMs consumed in operations. This would further preserve baseline funding by reducing the initial HCM procurement quantities and relying on an open production line and contingency funding to rebuild the inventory.

Finally, the HCM could increase the capability of legacy platforms, including the B-52, F-15E, F-16, and F-35. Currently the B-52 is the only platform capable of employing the ALCM/CALCM family of weapons. As part of the strategic arms treaties, the B-1B and B-2 both lack sufficient internal storage to employ the nuclear ALCM and by extension the CALCM. Since the HCM would be very similar in size and shape to the X-51A, the B-52, F-15E, F-16, and F-35 should be capable of employing the HCM, but the B-1B and B-2 would be unlikely to have this capability.

Recommendations

Hypersonic flight has the potential to make significant contributions to airpower in the next few decades. The technology has approached the maturity level required to make the transition from the lab to operational systems. Making this transition successfully is neither trivial nor impossible, but requires vision and leadership. The following recommendations serve as a guide to ensure the potential contributions are realized during a particularly austere fiscal environment in an increasingly volatile and uncertain world.

Sustained Research and Development

Basic and applied research works best with sustained funding. Start and stop efforts are less efficient, as test and prototyping facilities are built to support projects and then closed when programs are cancelled. Perhaps even worse, the intellectual capital developed during programs is degraded as engineers and scientists transition to more lucrative fields of technology. Hypersonic research has already experienced this setback at least once. According to Peebles, the optimism that fueled ramjet and scramjet research in the 1950s and 1960s was replaced with pessimism and declining budgets during the 1970s leading to the demise of the infant scramjet industry. Contributing to this outcome was a re-focusing of development needs on near-term requirements driven by the Vietnam counterinsurgency experience and economic morass of the 1970s.[71] As the nation again transitions from counterinsurgency and fiscal austerity, it is imperative to maintain hypersonic research and development at sustainable levels to avoid the inefficiencies associated with large funding variances. Following the X-51A program, the logical next step is a HCM technology development program to mature and demonstrate the remaining key technologies in support of a HCM acquisition program.

Sustained Procurement

Following a successful development phase, the USAF should pursue sustained procurement for the HCM. A highly effective HCM could easily become the weapon of choice in future contingencies as the recent experiences of Afghanistan and Iraq will likely dampen the appetite for conducting additional open-ended ground operations. As a result, the USAF could experience a HCM shortage without a continuously open production line. For example, the USAF had to place an "emergency order" for 322 CALCMs in January 1999 following the depletion of the inventory during Operation Desert Fox.[72] While the contract to fill this order was underway, the inventory dropped to around 100 CALCMs in March 1999 as a result of the air campaign against Serbia.[73] In addition to guarding against shortfalls, maintaining an open production line allows the assumption of some risk regarding the inventory size. The inventory could be sized based on the most extreme single contingency and replenished after any lesser contingency. In fact, it might be possible to replenish consumed inventory with supplemental contingency funds, conserving the USAF topline for other priorities.

Conclusion

By 2032, advances in radar and computer processing will create an extremely challenging threat environment. Airpower will need new capabilities to maintain an offensive capability against top of the line IADS. Prosecuting time sensitive targets will remain a priority requirement for commanders. After decades of research, hypersonic flight is on the verge of providing a solution to defeating an advanced IADS and prosecuting time sensitive targets. The once mythical scramjet has been demonstrated at hypersonic speeds and is being proven in the hydrocarbon fueled X-51A demonstration program, but success is not yet guaranteed.

Sustained funding for hypersonic technology development with the specific objective of acquiring and deploying an air-breathing HCM is the best approach to ensuring the future capability of the USAF. At present, it is equally important to guard against technical overreach. The temptation to pursue a hypersonic bomber must be avoided. Current materials support the design of a HCM with a relatively short duration single flight, but may be unsuitable for extended and repeated hypersonic flights. Even if all of the technical challenges could be solved for a hypersonic bomber, the increased life cycle cost would be substantial. The best approach is to invest in higher capability munitions and lower cost platforms. Once fielded, the HCM production line should be sustained to ensure an adequate inventory in an uncertain world.

Notes

1. Lt Col Jonathan M. Letsinger, "Hypersonic Global Strike Feasibility and Options" (master's thesis, Air University, 2012), 1. This paper uses the same definition of prompt global strike developed by Lt Col Letsinger. The eight hour definition of prompt global strike is measured from the President's decision to launch until weapon detonation.

2. Gordon Swanborough and Peter M. Bowers, *United States Military Aircraft Since 1909,* (Washington DC: Smithsonian Institution Press, 1989). Fighter aircraft were selected for this due to the larger number of data points and better consistency of aircraft mission. The following data were obtained from this source:

Aircraft	Operational Year	Top Speed (mph)		Aircraft	Operational Year	Top Speed (mph)
Wright Model A	1908	44		P-51B	1943	440
Thomas D-5	1914	86		P-47M	1945	470
DH-4	1917	124		F-80A	1946	558
Spad XIII	1918	138		F-84B	1947	587
PW-9	1925	155		F-86A	1948	675
P-1A	1926	160		F-94C	1951	585
P-12B	1929	166		F-89D	1954	636
P-12E	1931	189		F-84F	1954	695
P-6E	1931	198		F-102A	1956	780
P-26A	1933	234		F-100D	1956	892
P-30A	1935	274		F-104A	1958	1,404
P-36A	1938	300		F-106A	1959	1,327
P-35A	1940	290		F-101B	1959	1,094
P-39D	1941	368		F-105D	1961	1,390
P-40B	1941	352		F-111A	1967	1,650
P-38E	1942	395		F-4E	1967	1,500
P-47B	1942	429		F-15C	1980	1,650
P-51A	1943	387		F-16C	1981	1,320

3. Nicholas, Ted, and Rita Rossi, *U.S. Military Aircraft Data Book, 2011* (Fountain Valley, CA: Data Search Associates, 2010), 1-6. The following data were obtained from this source:

Aircraft	Operational Year	Top Speed (mph)
F-18E	2001	1,368
F-22A	2005	1,650

4. Dennis R. Jenkins and Tony R. Landis, *Hypersonic: The Story of the North American X-15* (North Branch, MN: Specialty Press, 2003), 247
5. Nicholas J. Willis and Hugh D. Griffiths, *Advances in Bistatic Radar* (Raleigh, NC: Sci Tech Publishing Inc., 2007), 94.
6. Arendt G. Westra, "Radar verses Stealth: Passive Radar and the Future of the US Military Power," *Joint Forces Quarterly* no. 55, (4th Quarter 2009), 140.

7. Ibid., 142.
8. Letsinger, “Hypersonic Global Strike Feasibility and Options” (2012), 8-10.
9. Ibid., 13.
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