Martin Summerfield and the first USA operational liquid-propellant rockets

Leonard H. Caveny[1]
Consultant,
Fort Washington, Maryland 20744 USA

Abstract
Martin Summerfield (1916-1996), a California Institute of Technology graduate, pioneered US rocket propulsion. In 1940, he began working for Theodore von Kármán on the liquid-propellant rocket jet-assisted takeoff (JATO) project. The necessary propulsion advances furthered the space exploration visions of Frank J. Malina (1912–1981), his lifelong friend and colleague. The facilities they initiated, by 1945, became the Jet Propulsion Laboratory. Summerfield's rockets were flight tested in 1942. From 1942 to 1945, as a founder of Aerojet Engineering Corporation, Summerfield developed liquid-propellant propulsion systems. Aerojet's Project-X program powered the Northrop MX-324 flying-wing demonstrator using pressurized nitric-acid/hydrocarbon propellants.

1. Introduction

This paper builds on and draws from the 2011 history of Martin Summerfield's life and career (Ref. 1). The focus is on his liquid-propellant rocket engine technical contributions between 1940 and 1945. His early professional history and contributions are intrinsically intertwined with Theodore von Kármán (Ref. 2) and Frank J. Malina's (e.g., Ref. 3) visions, leadership, and contributions. Dozens of America's aerospace leaders, early in their careers, stepped from their difficult Great Depression educations directly into World War 2 technology leadership positions and made sustained and historic aerospace contributions. Martin Summerfield and Frank J. Malina are among them.

Most people associate Summerfield with solid-propellant rocketry and will be surprised to find this paper deals with his 1940s successes with liquid-propellant rockets. By the time he left JPL in 1949, few in the US, other than the Werner von Braun team, had more hands-on experience and success in liquid-propellant propulsion than he had. The paper addresses the view that by 1945, the Malina and Summerfield rocket propulsion accomplishments exceeded those of Robert H. Goddard (1882-1945), the American rocket pioneer.

2. Early Years

1.1 New York and Brooklyn

Martin Summerfield was born in New York City on 20 October 1916 to Russian Jewish immigrants, Jacob and Augusta (Tobias) Summerfield. His father died during an operation to correct a breathing problem. Martin Summerfield was not yet age five. His mother was run over by a truck and killed when he was thirteen. As an orphan, Summerfield lived in the Brooklyn part of NYC with relatives who owned a grocery. In conversations, he discussed how he strived to avoid a life of working in a grocery. At the suggestion of his Brooklyn College physics professor Bernhard Kurrelmeyer (1903-1985), he applied to California Institute of Technology (aka CIT, Cal Tech, and Caltech). To Summerfield's surprise, he was accepted, enabling him to extend both his studies and associations.

2.1 Caltech

Martin Summerfield began his Caltech assistantship working in Professor Ira Sprague Bowen's (1898-1973) optical physics laboratory. He related how he spent long hours taking, processing, and interpreting spectral plates. Eventually, he became Professor John Donovan Strong's (1905-1992) first PhD student. He received a MS in 1937 and a PhD magna cum laude in 1941, both in physics from the California Institute of Technology. (At age 23, Summerfield finished the requirements for his PhD around June 1940, a little late for the 1940 formal graduation.)

Even after he was well into his Caltech graduate studies, Summerfield had no illusions about gaining employment as a scientist because of the Great Depression. In the 1940s, however, his associations with Professor Kármán, J. Malina, and the modest technological build-up changed everything. He was soon immersed into a lifelong whirlwind of sustained activity, leadership, and contributions. For more on Summerfield's early years and his manner see Ref. 1.

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[1] Fellow AIAA, Leonard Caveny joined Professor Summerfield's staff in 1969 and interacted with him after Summerfield left Princeton in 1978. L.Caveny@verizon.net 26 May 2013

3. Guggenheim Aeronautical Laboratory of Caltech (GALCIT)

A little background inserts Martin Summerfield into the illustrious history of Caltech's GALCIT (Guggenheim Aeronautical Laboratory of Caltech), precursor of the Jet Propulsion Laboratory (JPL). The dynamics of Caltech's president recruiting von Kármán and establishing him as head of GALCIT in 1930 are nicely explained in Chapter 3 of Gorn's, *The Universal Man*[4]. In 1934, Frank J. Malina, a Texas A&M engineering graduate began his graduate studies as a von Kármán scholarship student. Joining with other rocket enthusiasts, Malina became their leader. Their occasional explosions, prompted the stigmatizing name, "Suicide Club." In chapter 30, "Rockets and the 'Suicide Club'" of his autobiography,[2] von Kármán explains how rocketry established its most important foothold in the United States. In 1939, as a direct consequence of the Suicide Club's successes, analytical projections, and visions of applications interacting with National Academy of Science and Army Air Forces (AAF), von Kármán established the funded project referred to as GALCIT Project No. 1. Their primary task was to research and develop rocket motors for jet-assisted take off (JATO) of AAF planes. Summerfield joined the endeavor in 1940, too late to be a member of the pro bono Suicide Club, but just in time for a paid position. Later he recalled the opportunity, *". . . when I found I could make $200 a month working on this project, the decision was easy."* By then, the project, ably managed by von Kármán and Malina, was building substantial test facilities and planning office structures.

Summerfield and Malina, graduate school roommates, had previously established a lifelong friendship, when, having to support themselves they worked part time for von Kármán on his soil erosion projects.[5] In 1939, they designed a small sand-blowing tunnel at Caltech that was built as part of a proposal to build a large outdoor moveable soil-blowing tunnel.

3.1 Working for GALCIT Project No. 1

Summerfield began work a year before GALCIT's first major success, the demonstration of solid-propellant Jet Assisted Take Off, see Fig. 1. For the demonstration, the AAF selected the lightweight and modern Ercoupe, less than a 450 kg including the pilot. The JATO requirement was ~0.8 kN total thrust for 12 seconds. Parson's motors each used 0.9 kg of a black-powder variant pressed in 4.4 cm diameter tubes between about 28 cm long, < 2-day shelf life. His historic potassium perchlorate and asphalt (case bondable) composite-solid propellant was invented later, in June 1942. They were joined by theoretician Hsue-shen Tsien (now transliterated as Qian Xuesen) von Kármán's brilliant and invaluable assistant, whose complex contributions and involvements are covered more fully in Ref. 1.

Liquid-propellant rocket development

The GALCIT liquid-propellant team accepted much larger total impulse and system complexity challenges. In July 1940, von Kármán assigned Summerfield responsibility for developing the liquid-propellant rocket for the JATO system. Summerfield was skilled in optics and spectroscopy. However, von Kármán immersed him in fluids, chemical kinetics, and heat transfer challenges, i.e., aerothermochemistry in von Kármán's vernacular. He never had a course from von Kármán.

a) Ercoupe takes off with six black-powder solid propellant JATO units, each delivering ~0.12 kN for ~12 sec. First US JATO flight was 12 August 1941. Pilot Capt. Homer A. Boushey (von Kármán master's degree graduate) agreed to the risky test; a week earlier a JATO motor experienced an "explosive failure" in level flight[5]

b) Prelude to first flight on rocket power only (propeller removed and 12 rather than 6 JATO units) on 23 August 1941. Clark B. Millikan, Summerfield, von Kármán, Malina, and Boushey gathered around the Ercoupe wing.

Fig. 1 These well-known photos connect Summerfield with the solid-propellant JATO. Summerfield was assigned responsibility for developing the liquid-rocket JATO and did not devote much time solid-propellant JATO.

Summerfield's assignment was central to the urgent program. GALCIT would soon learn the AAF officials would threaten cancellation when they were not satisfied with the progress or management. This programmatic technique was inherent to Summerfield's manner; he understood it and he applied it. For the demonstration, the AAF selected the newly operational twin-engine Douglas A-20A, known for its good flying characteristics. The variant used had a gross take-off mass of 8439 kg, as configured for the demonstration. During the test series, the mass was varied from ~7938 to 9072 kg. The JATO specification was for two units each delivering 4.45 kN for 25 seconds. The Summerfield-led liquid-propellant JATO system would enjoy success eight months after the solid-propellant success, see Fig. 2.

a) Douglas A-20A Havoc take-off with liquid-propellant rocket JATO from Muroc Army Air Forces Base (now Edwards AFB). (JPL 383-93 1942)

b) Principals Summerfield, Malina, Walter B. Powell, Major Paul H. Dane (pilot), and von Kármán. Perhaps HNO_3 ruined Summerfield's shirt. (JPL photo 1942)

Fig. 2 First demonstration of liquid-propellant rocket JATO in the US occurred on 15 April 1942.

Summerfield Firsts

All "firsts" referred to in this paper pertain to the US, some may have occurred earlier in Europe. During our 3 April 2013 conversation, George P. Sutton explained that before 1945 Summerfield in particular had no knowledge of the relevant propulsion specifics associated with the German advances.

By 1941, advanced development programs were classified. Thus, the US knew little about the substantial developments in German rocketry leading to von Braun's pumped LOX/alcohol powered V-2 (aka Aggregat-4 or A4) ballistic missile and Hellmuth Walter's pumped H_2O_2/hydrazine-hydrate-methanol-blend that powered the Messerschmitt Me-163B *Komet* interceptor. Both were operational in 1944. As explained in Ref. 1, the GALCIT Project No. 1 team knew little about the specifics of Goddard's progress. GALCIT and Goddard were not on each other's report distributions lists. Hence, all through WW-2, "discoveries and innovations" in the United States on classified technologies were often local and not advertised.

To simplify the discussion, liquid-propellant rocket discoveries and innovations involving Summerfield are listed, followed by specifics, quotations, and anecdotes:

- Fuel and oxidizer impinging jet injectors promoting rapid combustion (Ref. 6 p. 178).
- Chromium plating the nozzle's copper surfaces to reduce the erosion.
- Implementation of hypergolic ignition. Development and qualification of the liquid-propulsion system for a practical application, i.e., JATO.
- Design/supervision of permanently mounted liquid-propellant JATO engines for Douglas A-20A as an Aerojet Engineering Corporation product.
- Design, fabrication, and tests of regenerative cooled hardware, building on James H. Wyld's[7] advice to Malina (Ref. 8 p. 7 & 11).
- Sufficient understanding of unstable liquid-propellant rocket combustion to overcome major developmental problem.[9]
- Development/supervision of innovative jet driven pumps, not a success for liquid-propellant rockets.
- Quantification of nozzle exit-cone flow separation (which occurs as altitude increases).[10]
- Comparative quantification of all jet propulsion systems as applied to missiles and transonic aircraft.[11]
- Suggestion to use JPL's WAC-Corporal as a second stage atop a V-2, aka Bumper WAC,[3] leading to first US two-stage liquid-rocket system.

Summerfield and Malina made a series of US firsts, discoveries, and innovations[†,12] enabling the liquid-propellant rockets for JATO and other applications. Their forefront activities are evidenced in part by their patents, e.g., see Fig. 3. These 1943 filings remained under secrecy orders until after WW-2. The fact they were issued after the war, when patent examiners had a grasp of the prior art, testifies to their US precedence.

The Challenge

The solid-propellant JATO was strapped to one of the lightest and easiest civilian planes to fly, far from a combat situation. Summerfield's task was to get an over-loaded bomber off a short runway, i.e., a real combat system operating under adverse conditions. Fortunately, Summerfield had two capable principal assistants. Edward G. Crofut (d. 1968), designer and technician, became his assistant in 1941. Walter B. Powell (1917-1994), a Stanford University engineer and Caltech graduate student, was hired in September 1941. He made several important contributions and retired from JPL in 1981. Summerfield also had access to the knowhow of Malina and others of the Suicide Club. WW-2 urgency energized the teams and suppressed the bureaucracy. Summerfield relates one of his first tasks was to "cut the weeds with a hand scythe in August 1940 on the plot [where] we were to erect the first crude [liquid-propellant rocket] test stand."[13]

Consistent with von Kármán's zest for analyses to counter the negatives of "the heavy voice of experience (Ref. 2 p. 256)," Summerfield's calculations, coupled with von Kármán's tutorage, led to a series of innovations enabling the GALCIT Project No. 1 team to do in less than two years what Goddard had not been able to do in a decade.

Liquid-Propellant Rocket for JATO → 4.45 kN

AAF required a JATO system that could be readily supported and used in the field. This dictated a storable system, ruling out liquid oxygen. Starting with the experience Malina and John W. Parsons gained on oxygen-ethylene (Ref. 6 p. 176), Summerfield selected red fuming nitric acid, RFNA,[14] and gasoline. Test cells to simulate the JATO horizontal firings were completed in February 1941. As shown in Fig. 4, they were built into the side of the arroyo to catch the flying parts of failed rockets, thus the terminology "test pit."

They progressed from 0.9 and 2.2-kN in 7.6-cm internal-diameter chambers to 4.45 kN in the 10.2-cm internal-diameter chambers used in the flight test. Their first three rocket engines failed "explosively," because of ignition problems. If ignition was not instantaneous, propellant accumulating in the chamber eventually ignited causing an overpressure failure. To achieve rapid ignition, Summerfield designed impinging jet injectors for better atomization and prevented the spray from short-circuiting the spark plug. The terminology and vocabulary in the 1941 and 1942 reports are nearly the same as present day. The GALCIT team had already invented characteristic length (L*), character velocity (c*), mixture ratio, injector nozzles, area ratios, etc parametrics. The injectors are described as:

> "Six of these tips, manifolded together, inject gasoline; the remaining twelve, also manifolded, inject nitric acid. The tips are aligned so that the liquid jets impinge, dispersing the liquids in a fine spray."

With injector modifications, Summerfield solved the immediate problems and scaled up to a larger engine delivering 2.2 kN thrust[15]. Photographs give a sense of Summerfield's involvement. Summerfield in Fig. 5 is shown after his transition from his spectroscopist's clean darkroom to the soot and acid of the "test pit." The technician is the one with the necktie. They set up to test the engines in pairs (see Fig. 6) to simulate the Douglas A-20A application. As shown in Fig. 7, the flight engines were heavy-wall hardware.

For thermal protection of the nozzle and case, they designed, fabricated, and experimented with regeneratively cooled systems. An early prototype is shown in Fig. 8; note the copper heat-sink cooled segments in the nozzle. Chromium plating the nozzle's copper surfaces reduced the erosion, thereby extending the action time. The essential features were ejectable nozzle, shielded spark plug, combustion chamber, and nozzle, all heat-sink cooled. Note the shock absorbers on the nozzle-release mechanism to reduce the loads on the nacelle (Fig. 9), in case of an overpressure failure and nozzle ejection; this type of consideration followed him to Princeton.

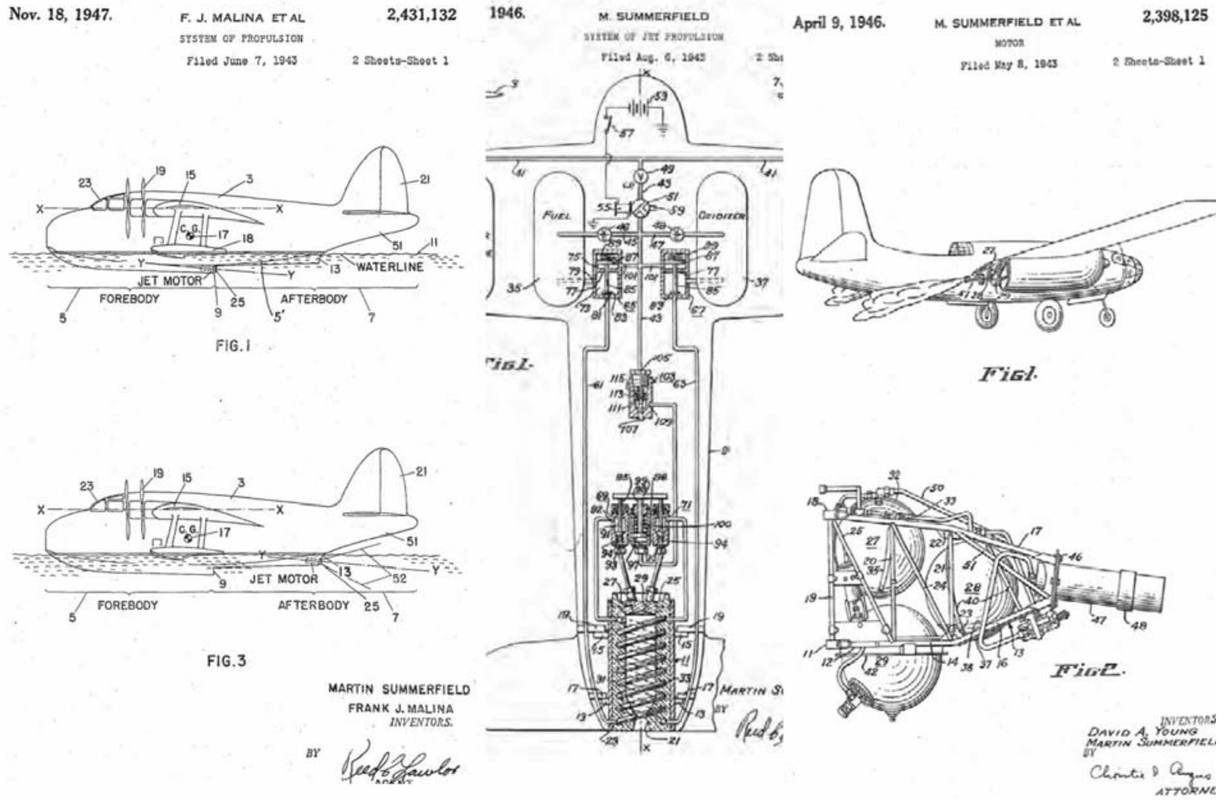
The September 1941 confidence building tests of 2.2-kN engines led to important decisions:

- To design a 4.45-kN -engine with a minimum duration of 25 seconds, essentially a 2:1 scale up.
- To request the AAF to provide an aircraft for flight tests.

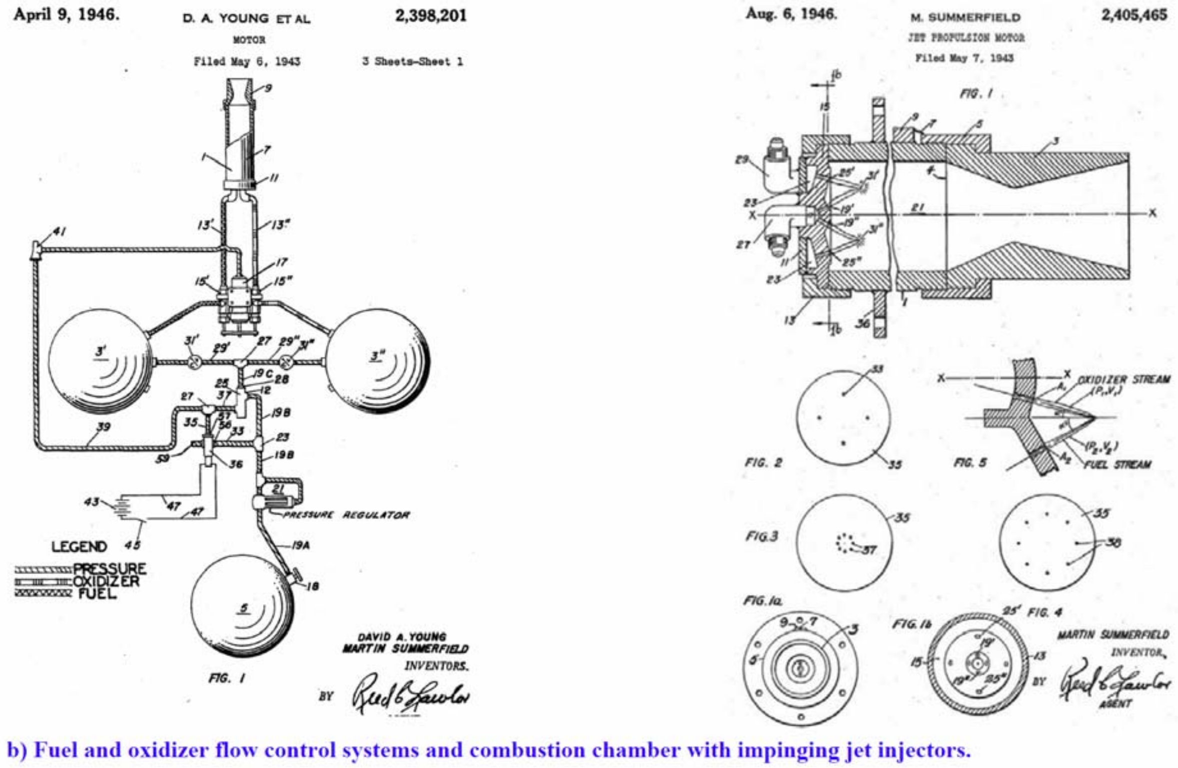
Tests began in October 1941 using a larger engine with a 10.2 cm internal diameter (12.7 cm outside diameter) and a larger improved injector and two shielded spark plugs. Malina and Summerfield probably expected the 33 % diameter scale-up to be uneventful. During this time, they experimented with regeneratively cooled nozzles and chambers. Summerfield also experimented with segmented nozzles with copper disks to improve the heat-sink and

[†] The uses of the words discovery, innovation, and first as in milestone accomplishments are most often parochial and certainly not worldwide since German, Soviet, Japanese, etc successes could not have been known during WW-2.

copper nozzle body sufficed, for the initial 4.45 kN 20-second demonstration, The configuration is represented capacity. They learned from their theory and experiments a rather simple uncooled, heat-sink combustion chamber



a) Basic patents covering Seaplane Under-hull Take-Off Assist, Rocket Powered Airplane, and. Liquid-Rocket JATO.



b) Fuel and oxidizer flow control systems and combustion chamber with impinging jet injectors.

Fig. 3 Summerfield's basic patents on liquid-rocket components and applications. The last three protect the components used in the production version of the Douglas A-20A nacelle mounted JATOs.

Fig. 4 Why it is called it a “Test Pit.” Firing 4.45-kN unit in Test Pit 3. (20 Feb 1942 JPL 383-236)

Fig. 5 Martin Summerfield and Edward G. Crofut working in Gas Propellant Rocket Test Stand in 1941. Crofut was Summerfield’s assistant, see Malina Ref. 6.

Fig. 6 Summerfield (r) with assistants Crofut and Powell in Liquid-Rocket Test Pit B testing the engines to be mounted in Douglas A-20A nacelles. (2 March 1942, six weeks before first flight on 15 April 1942)[27]

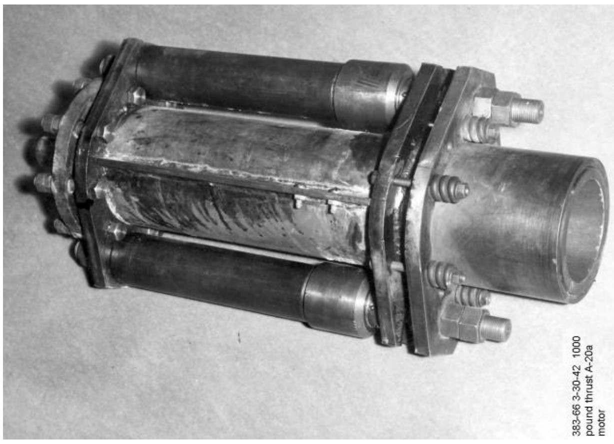


Fig. 7 The 4.45-kN engine used on Douglas A-20A had a 10.2-cm internal diameter. The schedule did allow time to qualify reduced mass hardware. (1942 JPL 383-66)

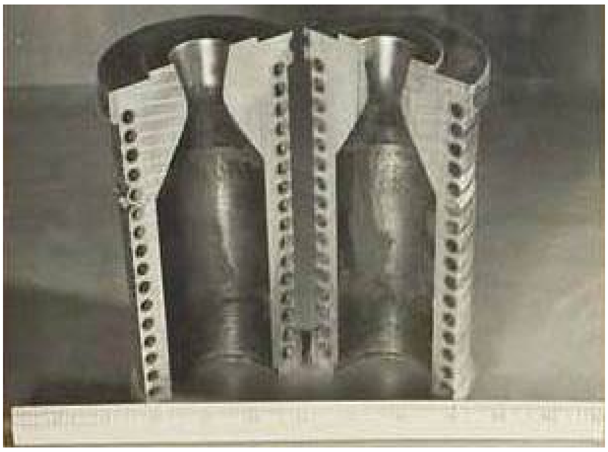


Fig. 8 Regeneratively cool chamber prototype put into practice James H. Wyld’s invention. (24 December 1941 JPL 383-177 low res)

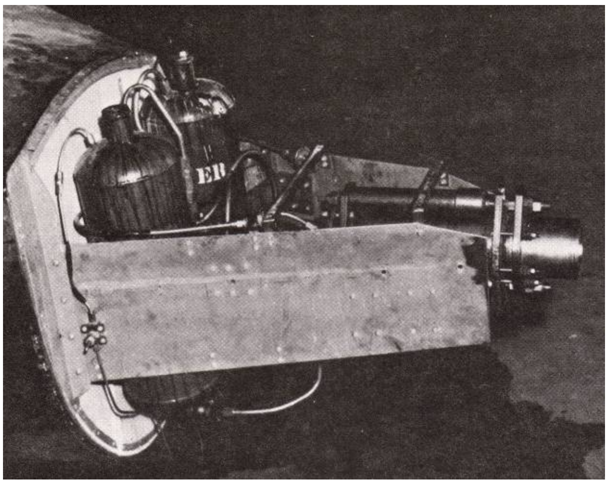
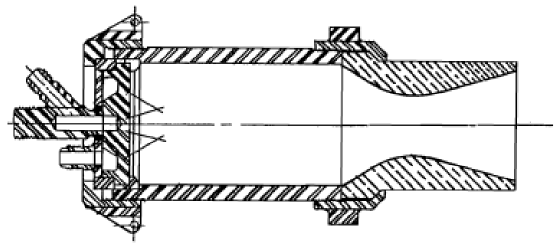


Fig. 9 RFNA-aniline fueled JATO prototype installed in a nacelle of the Douglas A-20A. The design specification was 4.45 kN for 25 seconds. (1942 JPL 383-68)

by the sketch from the heat transfer analysis as represented in Ref. 16 Chapter 11 p. 382. From the reference, by deduction, the flight test engine had the following primary parameters:

Heat-sink cooled; copper nozzle	
Chamber pressure	2 MPa
Combustion chamber length	~21.6 cm
Chamber internal diameter	12.7 cm
L*, V_{ch}/A_{throat}	~107 cm
Throat diameter	~4.6 cm
Oxidizer-fuel ratio	1.5 (optimum ~3)
Operating time	25 seconds

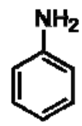


The 33% diameter scale-up caused multiple problems, including delayed ignition resulting in hard starts and combustion instability, referred to as “throbbing.” Welcome to rocketry! Once the sporadic throbbing began, if the engine was not shut off promptly, an overpressure failure occurred. Discussion of frequency, mode, and transient measurements were not noted. Throbbing was the sneak attack on GALCIT. The urgency of achieving success was fully understood. The next four months were spent fighting to overcome the combustion instability. In the meantime, the AAF was providing a Douglas A-20A twin-engine airplane, for tests in the spring of 1942. Its ample nacelles oriented away from the tail section must have been a factor.

Probably, the catastrophic “throbbing” inflicted on Summerfield’s rocket was a mysterious and new phenomenon for US developers. Perhaps, the term “combustion instability” (CI) had not yet been applied to liquid rockets. Seventy years later and after many careers devoted to anticipating and overcoming CI, several types remain unpredictable and difficult to overcome. Is experiencing CI and then applying a successful design fix a Summerfield first? Summerfield’s 1951 ARS Journal article[9] did not have any references referring to the specifics for unstable combustion in rocket engines. Maybe there was none to reference. Luigi Crocco published two papers the following year. In the case of Summerfield’s rocket, increasing the feed-line pressures and reconfiguring the feed lines were part of his eventual solution.

Summerfield’s group struggled to make their RFNA and gasoline system stable. The conventional wisdom dictated a very large combustion chamber for efficient combustion with hydrocarbon fuels. Summerfield, with von Kármán’s permission, had developed an efficient small injector/chamber system, by devising an oxidizer and fuel injector to achieve rapid mixing by tailoring the jet impingement. However, his gasoline fueled rockets continued to be plagued with combustion instabilities. They “throbbed” and suffered overpressure failures or flameouts. To contend with such events they devised a nozzle ejection system consisting of a spring-loaded bolt and damper arrangement. The goal was to ameliorate hardware damage of failure events short of a detonation. Summerfield hypothesized the instability resulted from the delay between injection and “start of combustion.” Even though he had greatly accelerated the injection, mixing, and ignition process, it was not fast enough. He achieved limited success, but realized he still needed more rapid ignition and combustion. Time was running out. After the wartime restrictions were lifted, Summerfield published his explanation for the unstable combustion in liquid-propellant rockets.[9]

During Malina’s February 1942 visit with Lt. Robert C. Truax (destined for national recognition) at the Naval Engineering Experiment Station at Annapolis, Maryland, Ensign Ray C. Stiff, Jr. (later an Aerojet VP) suggested a German literature reference on the hypergolic (spontaneous ignition on contact) properties of nitric acid (HNO_3) and aniline (C_6H_7N) (Ref. 6 p. 167). From Dayton, Ohio, Malina sent a telegraph to Summerfield asking him to replace the gasoline with aniline.



Sprague relates,[21] "One memorable motion picture shows Summerfield carefully holding a glass beaker of aniline tied to the end of a stick. He took a tentative step; then poured the substance into a container of nitric acid. The chemicals instantly burst into a large flame, and the new formula was adopted." A few days later, Summerfield welcomed Malina with the good news; they had a “reliable, storable, liquid-propellant rocket engine.”

Figure 10 shows frames from the film demonstrating ignition produced by pouring aniline onto nitric acid (HNO_3), i.e., not the good-practices sequence. From all indications, Summerfield and crew quickly validated the new fuel using the rocket hardware that had been developed and tested. Then they committed their prototype liquid-propellant rockets to become *man-rated* for use on the Douglas A-20A. Be certain, the AAF and Douglas engineers knew the consequence of a rocket failure on takeoff.

First Liquid-Propellant JATO Take-off

The choice of pilots for the JATO demonstrations revealed an AAF's success-oriented approach. The Ercoupe pilot, Capt. Homer A. Boushey, Jr., and the A-20A pilot, Major Paul H. Dane, had both received Caltech master's degrees in von Kármán's program.

As shown in Fig. 11, fueling consisted of pouring the aniline into the fuel tank, filling the oxidizer tank from a pressurized RFNA tank, and charging the nitrogen supply. The 1942 procedures were risky for the crew. Photos a few years later show proper precautions were being implemented.

The weight of each nacelle prototype installation was about 225 kg, much more than the eventual operational systems. Propellant consumption rate was 2.6 kg/s, yielding a (low by present standards) delivered specific impulse of 1705 m/s. The initial series of test flights starting in April 1942 included 44 successive successful firings[6] and takeoffs. The test series leading to the first flight are (Ref. 17):

Fig. 10 Summerfield and Walter Powell demonstrating hypergolic nitric acid & aniline that enabled GALCIT engines to start reliably and run stably.[21] **(March 1942)**

Tests 1-6 were stationary and static tests

Test 7	14 April 1942	4:30 pm	Taxi run with jets
Test 8	14 April 1942	5:00 pm	Take-off, jets on part of ground run
Test 9	15 April 1942	4:40 pm	Yaw test in flight
Test 10	**15 April 1942**	**6:45 pm**	**Take-off, with jets**

[considered the first successful test]

In 1969, Malina[6] recalled the historic event: "The first JATO assisted take-off of the (Douglas) A-20A was made on the afternoon of April 15, 1942" and "During the flight tests, the JATOs were fired 44 successive times without failure."

The final test on April 24 acknowledged the developers. With Summerfield's assistants Powell and Crofut onboard as the operators, the jets were turned on at 3000 m and the velocity increased from 385 to 451 km/hr.[17] The robustness of the on-off-on type operation is the virtue of the hypergolic system.

Fig. 11 Loading Douglas A-20A Havoc equipped with two 4.45 kN "Liquid-Propellant Jet Units" at Muroc Army Air Force Base (now Edwards AFB), California. (April 1942)

The JATOs as configured demonstrated a ~30% reduction in take-off distances. This was sufficient for the AAF to understand how fully operational JATOs remedied several AAF problems caused by overloaded planes, short runways, primitive runways, etc. In the early days of WW-2, JATOs were important and urgently needed.

In less than two years, Summerfield went from spectroscopy to propulsion hardware. He became test-pit boss of the first US application of liquid-propellant rockets. The remarkable team of von Kármán, Malina, and Summerfield made history. The GALCIT Project No. 1 contributions were significant in several ways, i.e., helped to establish a technology base, stimulated more interest in missile propulsion, and validated a cadre of practitioners.

The AAF put its trust in a university team, knowing the risks involved were considerable. A burn through, plumbing rupture, fuel-flow problem, etc. would have endangered the flight crew. A case in point, one of the listed test objectives was to assess the effect of the jet "blast" on the airplane. On the first flight, exhaust jet heating damaged the elevator, a problem that was expertly remedied. Very quickly, the Aerojet Engineering Corp. industrial team took charge; a production version of the JATO unit was developed and flight tested on the Douglas A-20A on 8 January 1943.[18] In two and half years, as his first job, Summerfield designed a first-ever US operational liquid propellant rocket, fought it through a difficult development process, participated in flight qualification and proof-of-principle testing, and managed the design team producing the production model.

4.1 The "GALCIT Project No. 1 Early Team" in Retrospect

In the 1930s, rocketry was not considered a serious endeavor, certainly not for universities.

As if by design, the tactic of bringing a fresh view to a difficult development was invoked and Summerfield joined the team in July 1940 (Ref. 2 p. 251). Summerfield had the ability to learn easily another's field. He did so for rocketry, and he interpreted and used the Malina and Suicide Club expertise as starting points for the next level of innovations. Von Kármán's manner promoted the open exchange concepts, approaches, and information. In this environment, the combination of colleagues and personalities produced a *ratcheting up* process, surpassing the closed-approach of Goddard. Collectively the group enjoyed the strength of its convictions, but was a little concerned by many of their peers believing rocketry to be "Buck Rogers" (Ref. 2 p. 243). The reader will note that as a defensive measure, the Caltech group members used the euphemism "jet propulsion" in many titles, the most prominent being the <u>Jet</u> Propulsion Laboratory, another being Aero<u>jet</u>, and yet another, the name of the *Journal of the American Rocket Society* being changed to *<u>Jet</u> Propulsion* in 1954 after Summerfield became the editor.

The GALCIT Project No. 1 leaderships demonstrated their intellectual gifts and their grasp of jet propulsion concepts (as they pertain to applications) in the winter of 1944 report[11] prepared by von Kármán, Malina, Summerfield and Tsien. They quantitatively compared the potential of solid rockets, liquid rockets, thermal jet engines (such as the aeropulse used in V-1), ramjet, and turbojet for a range of applications. Planners with access to this document gained the essential insights into where to make long-term major investments in new systems and what nature allows them to aspire to. Summerfield contributing, with his mentor and peers, to these types of assessment gave him unique systems engineering experience.

4. Working for Aerojet

" . . . without . . . JATO there would be no Aerojet"[21]

5.1 Aerojet: What Summerfield Experienced

The well-known history of Aerojet Engineering Corporation being organized toward the end of 1941 (after the solid-propellant JATO on the Ercoupe success) and incorporated on 19 March 1942 (a month before the liquid-propellant JATO on the Douglas A-20A success) will not be repeated here.[19] The Aerojet founders were von Kármán, Malina, Andrew G. Haley (von Kármán's attorney), Summerfield, Parsons, and Edward S. Forman. Authoritatively written Aerojet histories providing both specifics and insights into Summerfield's participations include three prepared by retired Aerojet employees (Refs. 20, 21, & 22),[23] historians Winter and James[24], and historian Hunley.[8,25] George S. James spent 18 years at Aerojet; Summerfield answered 22 specific questions posed by Winter in 1991; and Hunley interviewed Summerfield in 1994.

A concise history of the Aerojet's first two years involves two principal endeavors. JATO, the better-known endeavor, got the principals started in their comfort zone. The second, Project X, a highly classified endeavor, took those involved out of their comfort zones. Summerfield is listed [26] as Project X Coordinator in 1944.

JATO Production

Firstly, the principals in the Aerojet startup were confident of their abilities to develop, qualify, and manufacture JATO systems and believed they could sustain a profitable auxiliary propulsion business as a step toward their lofty goal of main propulsion systems for space exploration. Aerojet's first <u>development</u> contract was an order from the

Navy's Bureau of Aeronautics in early 1942 for experimental liquid-propellant engines for the Naval Engineering Experiment Station at Annapolis. Aerojet was given $20,500 and six months to do the job.

Aerojet's first production contract, in May 1942, was for 60 experimental-type liquid-propellant 4.45 kN JATO units and two droppable units for the AAF. The two contracts boosted Summerfield, vice president and head of Liquid Rocket Section, into being a key technologist in the fledgling organization. The previous two GALCIT successes were *innovation and integrated-system* feats. Suddenly, Aerojet's survival depended on Summerfield structuring a liquid-propulsion hardware program and a staff capable of design and production with urgency.

Soon, most of the production was for the Navy, since it had more applications than the Army did. The Navy pursued several JATO projects simultaneously, both solid and liquid. Most of the Navy JATOs were for large seaplanes taking off under difficult conditions.

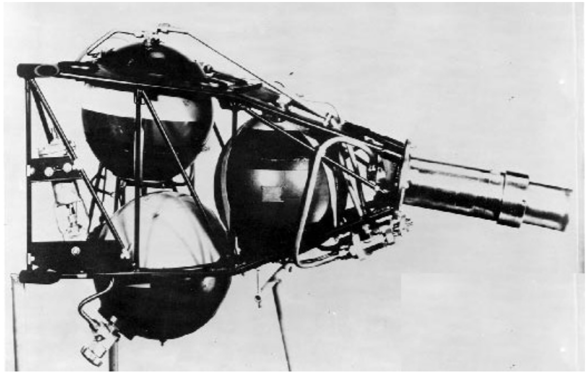


Fig. 12 Production JATO Engine for Douglas A-20A. Flight weight configuration is the same as the Summerfield & Young patent 2,398,125 filed 8 May 1943. Flight system was half the mass of the demonstration prototype. (Photo from AIAA website)

Aerojet set the standard with its initial product-improvement of the Douglas A-20A JATO. As Charles Ehresman explains,[27] the XLR1-AJ-1 production version (shown in Fig. 12) had 50% less mass and was much simpler to operate than the GALCIT prototype. The production version used spherical thinner-wall tanks in a tubular frame; the self-contained JATO could be toggled on and off by the pilot (see Ehresman figures 8 and 9). Summerfield and Aerojet delivered a man-rated system fabricated from flight-weight components, while having to compete with others for wartime material and component priorities. Three of the patents shown in Fig. 3 apply to the primary components. Summerfield's section continued with many innovations, e.g., common bulkhead fuel and oxidizer tanks, parachute recovery of droppable JATO, and impact-shock absorbing systems.

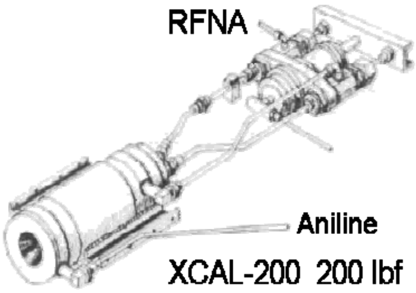
Project-X

Secondly, the highly classified Project X, the Northrop XP-79 rocket powered flying-wing interceptor, was the primary reason the Army caused Aerojet to happen and it attracted its illustrious staff. The Army's urgency resulted from awareness of the Messerschmitt progress on rocket-powered interceptors (e.g., Me-163, 9.33-m wingspan). The Northrop XP-79 (8.5-m wing span) featured a cockpit where the pilot lay in the prone position, which theoretically allowed him to withstand up to 20 g. An AAF contract with Northrop for three XP-79s was signed in January 1943. Under subcontract, Aerojet developed the first rocket systems to power a piloted US airplane. The flying wing eventually morphed to configurations known in the last two decades as blended-wing bodies.

In 1942, an AAF rocket-powered pursuit plane was viewed as a game changer, capable of unique attack tactics and maneuvers.[28] A concise account by Winter and James (Ref. 24 p. 683) includes Summerfield's role in the pertinent specifics of the first US sustained rocket-powered aircraft flight:

> "The contract was signed in January 1943, with Aerojet as the subcontractor to provide the [8.9 kN] 2000 lbf thrust nitric acid & aniline rocket power plant. Aerojet designated it the Aerotojet, or XCALR-2000A-1, though to maintain top secrecy at Aerojet it was simply called Project X. (The designation denoted Aerojet Experimental Cooled Liquid- Fuel Rotary Engine, Design A.) Three scale wooden mockups of the plane were built (by Northrop) to serve as test gliders. One of these, designated the MX-324 [9.8 m wingspan], was fitted with a smaller Aerojet of [0.9 kN] 200 lbf thrust called XCAL-200. Pressure-fed and using RFNA and aniline, it had a cast aluminum combustion chamber and copper nozzle and was restartable in the air. But development of the project was beset by many delays owing to its complexity and it was not until 5 July [1944], at Harper Dry Lake, near Barstow, California, that MX-324's first powered flight was made. The project was so secret that only a few people then knew of it. Among the handful of witnesses were Aerojet President Haley; Ernest J. Vogt, Aerotojet Project Engineer; and Martin Summerfield, titulary [sic] the Project Coordinator but de facto head of the project from its design and finance to arranging the tests. . . . As in the XP-79 configuration, the pilot, Harry H. Crosby, lay in the prone (MX-324) cockpit to withstand the high pull acceleration and also to reduce the plane's drag. The plane was first towed to [2440 m] 8000 feet by a Lockheed P-38 Lightning, then the tow cable dropped and Crosby opened the pressurizing lines for feeding the propellants to the combustion

chamber where they ignited spontaneously. The powered flight took 4.3 min with no difficulties and the landing was smooth. Crosby made several other similarly successful powered rocket flights, yet the project itself continued to face serious difficulties, especially the XCAL-2000-A (pumped fuel) engine."



The MX-324 powered by the Aerojet placeholder XCAL-200 is shown in flight in Fig. 13. The Wright Field aeronautical engineer on the project was Courtland D. Perkins, later Summerfield's Princeton University department chair for 23 years. In his 2 October 1964 letter to NASA historian E. E. Emme, Summerfield reminded him the Aerojet powered MX-324 was the first US plane to fly under rocket power. In doing so, he neglected to include that in 1941 he witnessed the Ercoupe (without a propeller) lifting off under GALCIT solid-propellant rocket power (Fig. 1). The magnesium constructed XP-79 variant designated as the XP-79B flew on 12 September 1945 using two turbojets, but never under rocket power.[28] History of the rocket engine's development challenges is in a following section.

In 1943, during the press of establishing Aerojet, Summerfield filed five basic patent applications pertaining to liquid engines, which were issued after WW-2 and all assigned to Aerojet Engineering Corporation (see Fig. 3).

6.1 Pumped Liquids

In September 1942, Summerfield announced, "Development work on propellant pumps and driving units is underway . . ."[29] That was just the beginning. Propellant pumps were one of the technologies where GALCIT-Aerojet came up short compared to the operational pumps Hellmuth Walter developed for Messerschmitt.

Sections 6, 7, and 8 (pages 320 to 344) of Chapter 10 in Tsien's compendium,[16] written in collaboration with Summerfield, discuss the Aerojet liquid-propellant pump developments and problems. Summerfield displayed broad knowledge of the pump design and development; he was the supervisor of the people developing the pumps. I know of no other 1940s reports by Summerfield on rocket engine pumps.

The innovations on Aerojet's Aerotojet/Centrojet liquid-propellant engines include a pump drive shaft rotated (8,000 to 10,000 rpm) by two canted rocket engines that also contribute axial thrust (see Fig. 14). Note the two canted nozzles on the lower right of the cutaway pictorial. The drive mechanism was akin to the ancient Hero steam-jet whirligig, but with real world unforgiving high-pressure seals for nitric acid. Of the published discussions on the initial Aerojet experiences with pumped liquids, the most authoritative is by George P. Sutton (Ref. 30 pp. 367-9). Since the Aerotojet/Centrojet concept did not succeed and, consequently, is of little continuing interest, the reader desiring more information is referred to Sutton and Ehresman. The attractiveness of the system was to avoid the problems of developing high-temperature, close-tolerance turbine drive pumps. The prototype engine failed catastrophically, during a well attended test. During our 3 April 2013 conversation, George P. Sutton explained Summerfield and he conducted the failure analysis. They determined faulty injected-propellant impingement during rotation caused unburned propellant to collect in the chamber, subsequently igniting and over pressuring the chamber. The *Conservation of Aggravation* ruled when the Aerotojet/Centrojet combustion means became the problem, i.e., the solution to an initial problem encountered a subsequent intrinsic problem of equivalent difficulty.

As those in the aerospace business know, one failed component in a system made up of heroically functioning components slams the door shut on immortality. In the case of Summerfield and his Aerojet staff the Aerotojet/Centrojet pump was that failed component. As the war was ending, systems not yet in production or no longer needed were shut down; the Northrop XP-79 interceptor was cancelled.

7.1 Wind down Aerojet

During WW-2, JATO units were credited with enabling numerous takeoffs, including helping fly out hundreds of wounded personnel, and rescuing crews of aircraft disabled at sea. The post WW-2 sales of JATO units plummeted. Sprague describes continued applications on dozens of planes for special situations and several examples of JATO enabled heroics, e.g., the 1948-49 Berlin Airlift.

Fig. 13 Northrop MX-324 (9.8-m wing span), experimental flying wing, sustained flight with Aerojet XCAL-200 pressure-feed liquid-propellant engine on 5 July 1944, an AAF funded US first, almost three years after the successful flight of the Messerschmitt Me-163.

5. Returning to JPL

"The Problem of Escape from Earth by Rocket"

In the words of Malina, Martin Summerfield returned to JPL from the Aerojet Engineering Corporation in the autumn of 1945 to take part in planning and research analysis of possible applications of rocket propulsion to space flight (Ref. 3 pp. 349, 371). Summerfield, for a time, was the Corporal missile program coordinator. In 1946, he is shown on the organization chart as Chief of Rockets and Materials.

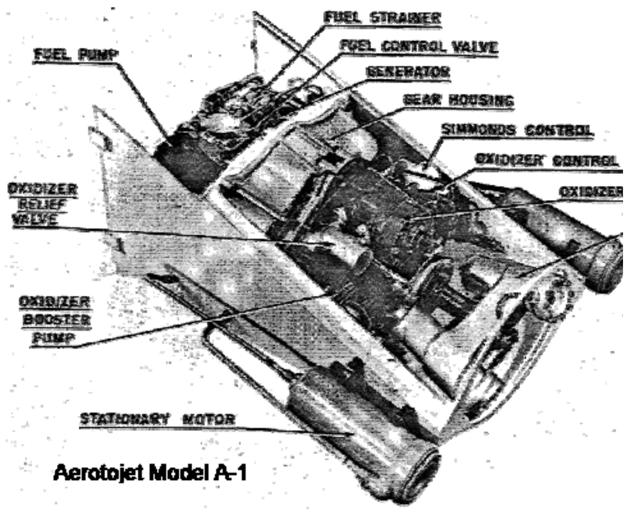


Fig. 14 Aerojet's Aerotojet Model A-1 (XCAL-2000-A) intended to power the Northrop XP-79 Flying Wing interceptor. Thrust 9.12 kN. Two canted thrust chambers mounted longitudinally on a drive shaft (exhausting at the exit plane) drove the turbopumps.

In January 1944, a second major JPL program, the ORDCIT Project[3, 31] was started to perform research and development on long-range jet propelled missiles for the Army Ordnance Department. The primary purpose of the ORDCIT Project was to obtain fundamental information to assist the development of long-range, jet-propelled missiles, together with suitable launching equipment. It progressed through the Private-A solid-propellant powered missiles (25.4-cm diameter) to the (76.2-cm diameter) Corporal short range ballistic missile. The WAC- (without attitude control) Corporal liquid-propellant rocket-propelled missile (30.5 cm diameter, 7.3 m long) was a small version of the 13.7-m long Corporal. Its liquid-propellant second stage engine was a derivative of the JATO engines, delivering 6.7 kN for 45 s. The WAC-Corporal is considered to be the first US developed sounding rocket. The project aligned with Malina and Summerfield's lofty goal of developing launch systems to explore space. Propulsion, missile aerodynamics, stability, and flight control technology and systems were integral parts of the new charter. In 1944, the facilities were well staffed and resident Army research and development personnel were involved. ORDCIT required a continual expansion of staff and facilities. After 1946, more of the reports had "long range,"[32] "high performance,"[33] or "escape velocity"[34] in their titles. In 1946, they formulated the "Malina-Summerfield Criterion" for step-rockets:[34] Each step of the optimum step-rocket has an equal ratio between its payload mass and the total mass of the step-rocket propelling that payload. Summerfield took on analyses, planning, and management responsibilities; his publications became more systems oriented.

In 1946, Summerfield suggested to Malina (Ref. 3 p. 175) using JPL's WAC-Corporal as a second stage atop a V-2. The stack became known as the Bumper-WAC. From 1948 to 1950, a series of eight US flight records were set, e.g., first two-stage liquid rocket, achieved record altitude of 393 km, and the first hypervelocity vehicle, 2.4 km/s.

In a 1982 paper[35] dedicated to the memory of his friend, Frank J. Malina, Summerfield modestly assessed the impact of the liquid-rocket engine development to which Malina contributed:

> ". . . it is immediately evident that today's rocket propulsion technology flows, in major ways, directly from the results of the work of the team that those two men (von Kármán and Malina) formed and led. We have only to take a quick look at the types of liquid propellant rocket engines in use - the injectors, the chamber configurations, the nozzle designs, the cooling techniques, etc., in the case of liquid propellant engines."

Summerfield's modest "two men" statement should be re-quantified to "three-men."

6. Post-War Irony - The Red Scare

What some refer to as the Second Red Scare (1945-57) was a complex web of investigations and prosecutions centered at the Federal Bureau of Investigation (FBI) and involving Congress (e.g., Senator Joseph R, McCarthy, U.S. Senator, 1947–57) and other US Government agencies. A group of prominent Americans struggled to prove they were and always had been loyal Americans. By the 1950s, the latter struggle impacted forefront technologies essential to enable future aerospace accomplishments.

Iris Chang's thoroughly researched *The Thread of the Silk Worm*[36] is a window on the Red Scare world of Summerfield's World War 2 colleagues. Chang explains how the Red Scare wrecked the US careers of two of Summerfield's GALCIT close associates, Malina and Hsue-shen Tsien (aka Qian Xuesen, the brilliant von Kármán protégé), and drove them out of the United States. In December 1946, Malina left JPL on leave of absence and never

again was employed by any aerospace organization. In 1959 he travelled freely in the US and, by 1965, apparently the FBI was no longer concerned about him. While Summerfield was never accused, his refusal to testify in court against his colleague curtailed his access to government research grants and contracts during most of the 1950s.

Malina and Tsien's plights bear directly on why JPL, Malina, and Summerfield did not receive their well-deserved acclaim for their pioneering propulsion and missile success. Summerfield's close friendship with Malina intensified the Red Scare scrutiny on Summerfield.

8.1 What Might Have Happened – Malina & Summerfield

By 1947, Summerfield and Malina's accomplishments and technical papers were attracting attention and influencing direction and policy. A Summerfield report, authored with members of his staff,[33] was an impetus for the Army establishing the Redstone Arsenal in Alabama as a rocket propulsion center and set in motion developments that produced Nike-Zeus and other systems. The Malina and Summerfield paper on achieving escape velocity is quoted as a modern rocketry successor to the visionary publications of Tsiolkovsky, Oberth, and Goddard. Indeed, Malina, proceeding stepwise to achieve a system capable of escape velocity, adapted a GALCIT liquid-propulsion system for the 1946 altitude-record setting WAC-Corporal flight series, which later evolved into Aerojet's workhorse Aerobee sounding rocket designed to explore the upper atmosphere and the threshold of space. Associated with the even more talented von Kármán, the self-assured Malina continued to make constructive use of the von Kármán international prestige and his connections to national leaders to pursue the frontier of space. As Malina explains,[3] he was conflicted by having to pursue technology goals the US justified primarily by defense needs. In the late 1940s, visions were insufficient to anticipate the commercial satellite industry and a large civilian space exploration agency.

7. Post War Assessment

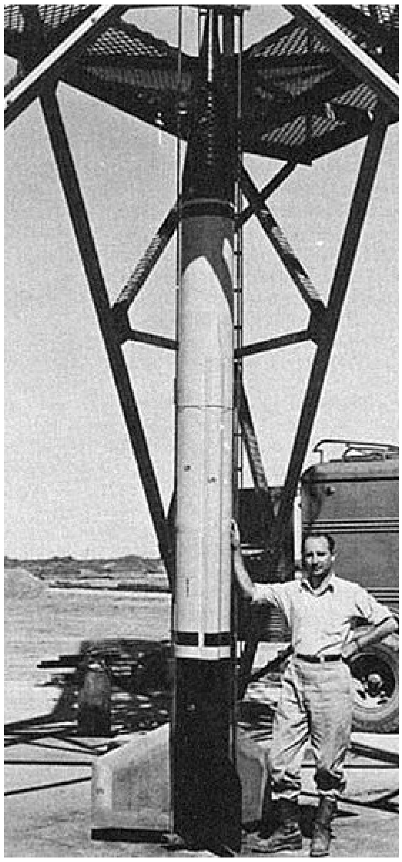
9.1 US and German mid-1940s Accomplishments

Some are beginning to understand the illusory history of the 1940s pioneering rocketry events, organizations, and leaders. Investigative journalist, M. G. Lord,[37] from her JPL vantage point, is emphatic about how the von Braun team received abundant praise and positive publicity, whereas Malina, with a solid record of accomplishments was hounded out of the US and his subsequent position with UNESCO. She adds that Summerfield's research was hampered.

Soon after WW-2, the specifics of the V-2 and Messerschmitt propulsion systems were widely published and praised. Meanwhile, even in the 1950s, disclosure and publications of the JPL and Aerojet accomplishments remained under secrecy orders. Some pertinent reports are still withheld from the public.

Two bases for comparing the relative accomplishments are the specifics of (1) the jet propulsion technology and (2) operationally fielded systems. By several measures, Germany's major investments fielded liquid-propellant rocket systems superior to those of the US.

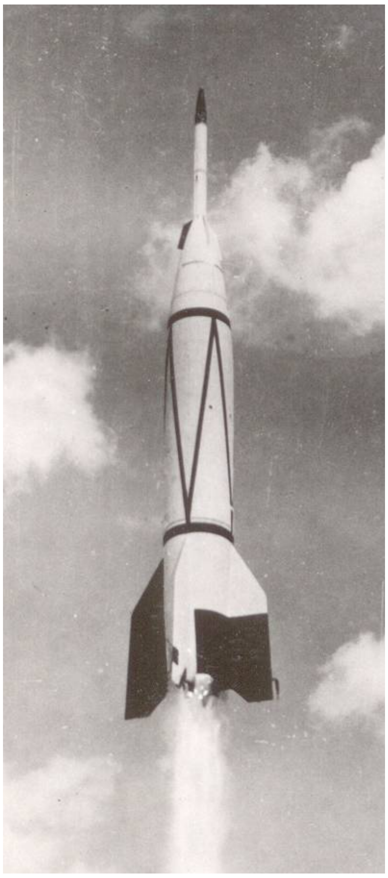
Over 300 Messerschmitt Me-163 *Komet* rocket power interceptors were produced and dozens flew combat missions. The Northrop XP-79 never progressed beyond an early prototype phase. Side-by-side technology comparison of the Me-163's HWK-109-509 A-2 engine, Aerojet's XCAL-200 (Fig. 13**)**, and the troubled XCAL-2000-A (Fig. 14) is a publication topic for others.[30,38] The Me-163 was powered by 16.7 kN thrust (variable from ~2 kN) Walter 109-509A-2 turbo-pumped bipropellant-rocket engine designed and built by the innovative Hellmuth Walter. George P. Sutton (Ref. 30 pp. 754-762) devotes eight pages to Hellmuth Walter and his Kommanditgesellschaft (HWK); he singles out the HWK 109-509, as the best know of the HMK aircraft engines. Sutton provides specifics on its configuration and praises HMK in general.



1945 Malina at White Sands Missile Range, New Mexico, with WAC Corporal second stage propelled by derivative of Summerfield's JATO engines, set US altitude records.

Assessments by Hunley,[39] a NASA historian, suffice by stating the high points of each nation's accomplishment without judging one better than the other. Hunley links technology progression of JATO, WAC-Corporal, Aerobee, and Titan. He believes JPL's (and thus Aerojet's) more wide-ranging and significant contribution was the development of a castable, composite-solid propellant that enabled more sophisticated solid propellants used on the Polaris and Minuteman missiles and the booster of the Space Shuttle.

Von Kármán, Malina, and several of their staff had major roles in inspecting German hardware and technology in Europe. Hence, he and Malina had a well-informed basis for assessing the relative merits of the US and German approaches. Summerfield and Malina preferred the US technology and while others in the US used the German designs as their starting points. The German missile guidance and control knowhow was another matter.



V-2 Rocket with WAC Corporal second stage, on 24 February 1949, set US altitude (393 km) and velocity (2.3 km/s) records

8. Conclusion

Upon moving to Princeton University in 1949, Martin Summerfield, for the most part, did not continue his pursuit of liquid-propellant propulsion. However, he was excited and wrote overview articles on the technology that orbited Sputnik and later enabled the US to orbit its first satellites and to explore the moon. Those articles cause readers to recall the visionary technical accomplishments of Summerfield and Malina laying part of the foundation in anticipation of such events.

What might have happened if the Red Scare had not thrown Malina and Summerfield off track? JPL very well could have led the national program to put the world's first operational satellites into orbit. In retrospect, the explanation of *what might have been* is easily stated.

Acknowledgments

The contributions of colleagues and archives access are greatly appreciated. The complete acknowledgements are in Ref. 1.

References

[1] Caveny, Leonard H., "Martin Summerfield and His Princeton University Propulsion and Combustion Laboratory," presented at AIAA Propulsion Conference, August 2011, AIAA Paper 2011-5711, 70 pages.

[2] von Kármán, Theodore with Lee Edison, *The Wind and Beyond: Theodore von Kármán Pioneer in Aviation and Pathfinder in Space*, Little, Brown and Company, 1967, 376 pages.

[3] Malina, F. J., "America' s First Long Range Missile and Space Exploration Program, The ORDCIT Project of the Jet Propulsion Laboratory, 1943-1946: A Memoir," *Essays on the History of Rocketry and Astronautics*, Vol. 2, 1971, International Academy of Astronautics, pp. 339-383.

[4] Gorn, Michael H., *The Universal Man, Theodore von Kármán's Life in Aeronautics*, Smithsonian History of Aviation Series, 1992, 202 pages.

[5] Malina, F. J., "Memoir on the GALCIT Rocket Research Project, 1936-38," *Proceedings of 1st International Symposium on the History of Astronautics*, International Academy of Astronautics, 1967.

[6] Malina, F, J., "The U.S. Army Air Corps Jet Propulsion Research Project GALCIT Project, No. 1, 1939-1946: A Memoir," 1969, printed in *Proceedings of the Third Through The Sixth History Symposia of the International Academy of Astronautics*, NASA Conference Publication 2014, Vol. II, 1977, pp. 153-201. (Page numbers are for original published typescript.)

[7] Wyld, James H., "Mr. Wyld Describes His New Motor," *Astronautics, American Rocket Society*, Vol.8, No.40, 1938, pp. 11-12.

[8] Hunley, J. D., Interview with Martin Summerfield near Princeton, N.J., 27 September 1994

[9] Summerfield, M., "A Theory of Unstable Combustion in Liquid Propellant Rocket Systems," *Journal of the American Rocket Society*, September 1951, Vol. 21 No. 5, pp. 108-114.

[10] Summerfield, M., Foster, C. R., and Swan, W. C., "Flow Separation in Over-Expanded Supersonic Exhaust Nozzles," presented at Heat Transfer and Fluid Mechanics Institute, Los Angeles, CA, 1948.

[11] von Kármán, Th. with contributions from F. J. Malina, M. Summerfield and H. S. Tsien, " Comparative Study of Jet Propulsion Systems as Applied to Missiles and Transonic Aircraft," Jet Propulsion Laboratory, Memorandum JPL-2, 28 March 1944 (declassified 22 October 1951, JPL Internal).

[12] Malina, F. J., “America' s First Long Range Missile and Space Exploration Program, The ORDCIT Project of the Jet Propulsion Laboratory, 1943-1946: A Memoir,” *Essays on the History of Rocketry and Astronautics*, Vol. 2, 1971, International Academy of Astronautics, pp. 339-383.

[13] Summerfield, M. and G. Edward Pendray Exchange of letters on accomplishments of Robert H. Goddard, June 1965.

[14] RFNA is a mixture consisting mainly of HNO_3, typically 4 to 14% dinitrogen tetroxide (aka nitrogen tetroxide or NTO), and a small amount of water ~3%. The mixture used in the initial JATOs is thought to contain 6 or 7 % NTO. The blend is often determined by the search for the best ignition characteristics.

[15] Summerfield, M. and Forman, Edward, "Progress Report on the Development of a Liquid-Propellant Jet Motor," Report 10 GALCIT Project No. 1, September 28, 1941, 14 pages.

[16] Tsien, Hsue-shen (Editor), *Jet Propulsion*, Jet Propulsion Laboratory, 1946, 818 Pages (JPL History collection document HC 5-392) Note on page 323: Chapter 10 Sections 6, 7, and 8 were written in collaboration with Dr. M. Summerfield of the Aerojet Engineering Corporation.

[17] Malina, F. J., “Take-off and Flight Performance of an A-20a Airplane as Affected by Auxiliary Propulsion Supplied by Liquid Propellant Jet Units,” Air Corps Jet Propulsion Research, GALCIT Project No. 1, Report No. 12, June 30, 1942.

[18] Emme, E. M., “Aeronautics and Astronautics Chronology,” 1940-1944, NASA pp. 39-49.

[19] The first commercial rocket company in the US, Reaction Motors, Inc. in New Jersey, was formed on 16 December 1941, by James H. Wyld and four others.

[20] Ross, Chandler C., “Life at Aerojet-General University - A Memoir,” The Aerojet History Group, 1981 (reprinted 1994), 97 pages.

[21] Sprague, Thomas H., *Aerojet - The First 50 Years*, March 1992, Self Published, 153 pages.

[22] Dorman, B. L., Gorden, R., Umholtz, P. D., Sprague, T. H., et al, *Aerojet: The Creative Company*, Aerojet History Group, Published by Stuart F. Cooper Company, Los Angeles, CA, ISBN 0-9659769-0-4 1995, 958 pages, pp. I-30 & I-31.

[23] References 20, 21, & 22 were written by people who knew Summerfield or interviewed the 1940 to 1949 coworkers of Summerfield. The first was published by Chandler C. Ross who joined Aerojet in 1943 and worked with Summerfield on pumps. The second is by Thomas H. Sprague in 1992. The third and more comprehensive volume was published by the Aerojet History Group in 1995. Portions of Sprague’s prose are referenced and used by the Aerojet History Group.

[24] Winter, F. H. and James, G. S., “Highlights of 50 Years of Aerojet, a pioneering American Rocket Company, 1942-1992, ”*Acta Astronautica*, Vol. 35 9-11, 1995, pp. 677-698.

[25] Hunley, J. D., “*The Development of Propulsion Technology for U.S. Space-Launch Vehicles,”* 1926-1991, Centennial Series of the Association of Former Students, Texas A&M University Press, 2007.

[26] Biographies of Aerojet Engineering Corporation Personnel, Aerojet Engineering Corporation, May 1944.

[27] Ehresman, C. M., “The First Operational Liquid Rocket for Aircraft Developed and Produced in Quantity in the United States,” Paper AIAA-2000-3280, 36th AIAA Joint Propulsion Conference, July 2000.

[28] Woodridge, E. T., “Northrop: the War Years,” History of the Flying Wing, Century of Flight, ~2003 and Woodridge, E. T., Winged Wonders, *The Story of Flying Wings*, Smithsonian Institute Press, 1983.

[29] Summerfield, M., Powell, W. B. and Crofut, E. G., "Development of Liquid Propellant Jet Unit and Its Operation on an A-20a Airplane,” Jet Propulsion Laboratory GALCIT, Report No. 1-13 and Supplement, 14 September 1942 (JPL Internal).

[30] Sutton, G. P., *History of Liquid Propellant Rocket Engines*, AIAA Library of Flight Series, 2006, 911 pages.

[31] “The ORDCIT Project,” *Engineering and Science Monthly*, Caltech, July 1946, pp. 12-14.

[32] Seifert, H. S., Mills, M. W., Summerfield, M., “Physics of Rockets: Dynamics of Long Range Rockets,” *American Journal of Physics*, Vol. 15, No. 3, May-June 1947 pp. 255-272.

[33] Summerfield, M., Shafer, J. I., Thackwell, H. L. “Applicability of Solid Propellants to High-performance Rocket Vehicles,” Memorandum No. 4-179 Issued 1 October 1947, Jet Propulsion Laboratory of the California Institute of Technology to Report on Research under ORDCIT Project Contract No. W-04-200 Ord-455, Army Ordnance Dept. (Reprinted in Astronautics, October 1962).

[34] Malina, F. J. and Summerfield, M., “The Problem of Escape from the Earth by Rocket,” JPL Publication No. 5, 23 August 1946; also “The Problem of Escape from the Earth by Rocket,” *Journal of the Aeronautical Sciences*, 1947, Vol. 14 No. 8, pp. 471-480.

[35] Summerfield, M., “Fundamental Scientific Questions in the Early Period of Rocket Propulsion Development,” *IAA History Symposia*, Vol. 6 and *AAS History Series*, Vol. 11, 1982, pp. 141-143.

[36] Chang, Iris, *Thread of the Silkworm, the story of Tsien Hsue-shen*, Basic Books, 1995, 329 pages

[37] Lord, M. G., *Astro Turf: The Private Life of Rocket Science*, Walker & Company, 2005.

[38] Ehresman, C. M., “Liquid Rocket Propulsion Applied to Manned Aircraft in Historical Perspective,” Paper AIAA-91-2554, 27th 36th AIAA Joint Propulsion Conference, June 1991, 12 pages.

[39] Hunley, J. D., “Comparative History of Rocket Development at Peenemunde in Germany and at the Jet Propulsion Laboratory in the U.S.A. from 1932 to 1945,” *Acta Astronautica*, Vol. 43, No. 1-2, pp. 61-62, 1998.