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Paper

All eyes were on Lieutenant Colonel James H. “Jimmy” Doolittle as he climbed into the cockpit of his B-25 shortly after 8:00 a.m. on April 18, 1942. His was the first in line of sixteen long-range bombers crowding the deck of the USS *Hornet*, positioned in the Pacific Ocean some 620 miles east of Japan. Doolittle’s plane had only 467 feet of deck ahead. The tail of the last B-25 hung out over the ship’s fantail. Doolittle steered his plane into position, aligning his left and nose wheels with two white hashmarks the *Hornet*’s crew had painted on the deck. Holding to those marks during takeoff would allow the B-25’s right wing to clear the ship’s superstructure by about six feet.¹

Before this mission few thought it possible that a land-based plane, fully loaded with thousands of pounds of ordnance, could take off from a carrier at sea. Doolittle, a legendary aviator who had reenlisted in the Army two years before at the age of forty-three after a decade in civilian life, had spent the previous five months studying and training in B-25s for this unusual mission. He stripped the planes

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Paper

of all unnecessary equipment (including the radios) and modified the gas tanks and carburetors for greater fuel efficiency. Doolittle found that on a carrier going full speed into a strong headwind, a B-25 could achieve minimum takeoff speed and be airborne in only a few hundred feet.

The mission that would come to be known as the Doolittle Raid was planned and executed in direct response to the Japanese attack at Pearl Harbor on December 7, 1941. Approval for an offensive air strike on the Japanese mainland came almost immediately from Army Air Force general Henry “Hap” Arnold. On April 2, 1942, the *Hornet* sailed from San Francisco accompanied by four destroyers, two cruisers, and a refueling ship. The force made rendezvous ten days later with the carrier *Enterprise* and her attendant fleet of support vessels. Task Force 16, as the joint armada was now called, fell into cruising formation headed due west across the Pacific. Those crew members not fully informed of the true nature of the top-secret mission could by now make a pretty accurate guess.

The plan called for the *Hornet* to take a position 500 miles from Tokyo on April 19, from which the B-25s would be launched. A day earlier and 120 miles short of the launch zone, however, the fleet spotted a Japanese reconnaissance vessel. Intercepted radio transmissions in Japanese convinced the *Hornet’s* officers their position had been compromised. Dive bombers launched from the *Enterprise* attacked and sank the enemy vessel. Doolittle ordered his men to their planes. They were going to take off now.

All the pilots’ previous training in short takeoffs had taken place on land at Elgin Field in Florida, where an outline of the *Hornet’s* deck had been painted on the runway to simulate the carrier. Persistent mechanical problems and equipment constraints limited the crews to only twenty-five flight hours in the B-25s and not a single practice takeoff from a carrier at sea. Doolittle himself had never before done it. When the deck crew pulled the chocks from his wheels and

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Paper

Doolittle revved the plane's engines, everyone onboard knew the entire mission was at stake. If Doolittle couldn't take off in 467 feet, it was over. If he could, then each successive plane had that much additional room for takeoff. The sixteenth and last plane would have a clear deck with a more than comfortable 820-foot margin.

Doolittle accelerated just as the *Hornet's* bow began recovering from a plunge into the wind-whipped thirty-foot waves. The deck was still rising when he achieved full speed and took off with room to spare. The crews of the other B-25s breathed sighs of relief. Within exactly one hour all sixteen planes were airborne and flying for Japan. The ships of Task Force 16 turned around immediately and sailed for Hawaii.

At that moment six hundred miles away in Tokyo, civil defense forces initiated a routine air raid drill that had been announced in the newspapers two days before. Planes took to the sky as barrage balloons (large inflatables tethered to cables and held in place high over cities to deter enemy aircraft from approaching overhead) were launched along the waterfront. Firefighters tested their equipment. The city's residents barely noticed, however. There had been no sirens that morning, and the drills were becoming so commonplace as to attract little attention. Few noticed when a twin-engine bomber approached the city from the north just after noon. (Doolittle had maneuvered to come in from that direction figuring the Japanese would concentrate their air defenses for an expected attack from the east.) After dropping its entire bomb payload in an industrial area of the city, the B-25 quickly descended in an S-pattern to rooftop altitude to evade any anti-aircraft fire or Japanese fighters that might be in pursuit (none were).

Joseph C. Grew, the U.S. ambassador to Japan whose repatriation the Japanese would prevent until later that summer, at first believed he was witnessing a training exercise, a mock dogfight among Japanese planes. Even when half a dozen large fires with black, billowing

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smoke broke out around the city, it hardly seemed possible this was an American attack. Father Bruno Bitter, the rector of Sophia University in Tokyo, would similarly recall that most people thought it was just another drill. But when they realized the sirens were real, he noted, “nobody could hold them back to go outside, to climb the roofs or the chimneys to get a better view.” An intense curiosity overcame everyone’s better instincts to seek shelter.²

Over the course of the hour, the American planes engaged military and industrial targets in five cities in Japan—Tokyo, Yokohama, Osaka, Kobe, and Nagoya—each dropping three 500-pound high explosive demolition bombs and one 500-pound incendiary bomb. None experienced any significant defensive fire from the Japanese. The sixteen planes continued west toward five Allied airfields in China. Deteriorating weather conditions and empty fuel tanks, however, kept every plane from reaching its intended rendezvous point. All either crash-landed short of the airfields or were ditched by their crew. One landed in Russia near Vladivostok.

Doolittle and his crew bailed out over Quzhou and, armed with the one phrase they knew—*Lushu hoo megma fugi* (I am an American)—received assistance from Chinese civilians and soldiers. Though he survived and was feted by Chiang Kai-Shek, Doolittle knew the bombings had caused little actual damage in Japan. He had lost his entire fleet of B-25s and had no knowledge of the safety or whereabouts of most of his crew. Doolittle wondered whether a court-martial awaited him back in the States. What Doolittle and his fellow airmen received was a hero’s welcome. Doolittle received the Medal of Honor, as well as a promotion to the rank of Brigadier General, and all eighty Raiders received the Distinguished Flying Cross. By directly avenging the attack on Pearl Harbor, the Doolittle Raid boosted the morale of Americans and marked a turning point in attitudes about the war. Japanese domination in Asia and the Pacific suddenly appeared vulnerable.

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Paper

In Japan, the effect was nearly as dramatic.

For a people with an almost spiritual belief their homeland would never be invaded, the Doolittle Raid shook their confidence to its core. The Japanese had absolute faith in the emperor. They believed officials who claimed the nation was invincible. That enemy planes had entered Japan unmolested and dropped bombs in cities across the country belied that notion. What else had the government lied to them about? Besieged for information after the bombing, Japanese military officials first sought to exaggerate the Americans' ruthlessness. They claimed entire fleets of bombers destroyed whole city blocks and killed thousands of civilians, including dozens of children machine-gunned to death in their schoolyard. As embarrassment over the surprise raid set in, however, the government reversed course and began downplaying the attack. Official releases stated the Americans' pathetic strike had caused minimal damage. Newspapers reported nine American planes had been shot down, an obvious lie. For senior officials, allowing the life of the emperor to be put in danger proved the worst humiliation of all. Just six weeks later, Japan sought to expunge the dishonor by attacking Midway Island (from which they suspected the Doolittle Raid had been launched). The disastrous defeat at Midway permanently weakened the Japanese navy and altered the balance of power in the Pacific in favor of the United States.

The Doolittle Raid started in motion still another chain of events in Tokyo. Infuriated that mainland America remained comfortably untouched, the Imperial General Headquarters demanded a retaliatory strike on the United States. The violation of their homeland convinced the Japanese of the need to respond in kind. Even an offensive that caused only minimal damage, no more than the marginally strategic scattering of bombs Doolittle had accomplished, would give Japan a moral boost. Just weeks after the Doolittle bombing, a simple directive went out to scientists and engineers at the Noborito

Institute to devise an offensive strike capability. The order was no more descriptive than that. Find a way to bomb America.

NOBORITO

The Ninth Military Technical Research Institute, more commonly called the Noborito Institute, occupied an expansive compound on a bluff above the Tama River in southwest Tokyo. Founded in 1927 by Captain Ryo Shinoda as part of the Army Science Research Institute, Noborito began as a small research division dedicated to covert warfare. Shinoda, a chemist who had studied at the prestigious Tokyo Imperial University, at first mined spy novels and movies for ideas about intelligence and counterintelligence operations. His staff tinkered with secret inks, miniature cameras, counterfeit foreign currencies, telephone wiretapping devices, and other tools of the espionage trade. Eventually the laboratory moved on to more lethal applications, including poisons and biological agents that could be used to destroy crops and livestock. By the outbreak of World War II, the division had grown to two dozen buildings and nearly one thousand employees. Shinoda himself would achieve the rank of lieutenant general.³

In summer 1942 Noborito began investigating ways to fulfill the retaliation directive. One early proposal called for long-range bombers to make one-way sorties from Japan to the U.S. mainland. After dropping the entire payload of high-explosive ordnance on Seattle, San Francisco, Los Angeles, or some other urban center on the West Coast, the crew would use the aircraft itself as a weapon, crashing it into some high-value target. Engineers dreamed up ways a bomber could fly all the way from Tokyo to New York. They'd have to strip the aircraft of all unnecessary equipment and install fuel tanks inside the fuselage, essentially turning the airplane into a flying fuel tank. The plan never advanced beyond a few design drawings, however. A more practical option called for a small bomb-laden aircraft equipped

with floats for water landings that could be launched from the deck of a submarine. The proposal was field-tested on September 9, 1942, when Warrant Officer Nobuo Fujita took off in a Yokosuka E14Y floatplane from a submarine that had surfaced off the Oregon coast. Fujita dropped two large incendiary bombs in the Siskiyou National Forest in the hope of starting a forest fire. His plane was spotted from a lookout tower, however, and response crews easily located where the bombs fell and contained the small fires. A recent rainstorm had also made the woods very damp and prevented the fires from spreading any further. Although the sortie was a “success” in that Fujita bombed his target and was safely retrieved after landing the plane alongside the submarine, the Imperial Navy canceled the project.

That same month, Sueki Kusaba, a major general stationed in Manchuria, was recalled to Japan and assigned to Noborito. Like Shinoda and nearly all other top scientists at the institute, Kusaba was a graduate of Tokyo Imperial University, the nation’s premier institute of higher learning, where he had studied applied physics. Upon arriving at Noborito he was placed in charge of a unit then experimenting with free balloons. Technicians were modifying weather balloons and barrage balloons to see whether a free balloon could transport ordnance great distances. Engineers at Noborito had first studied the concept of a balloon bomb in the early 1930s, when Lieutenant General Reikichi Tada led a program that designed a four-meter balloon capable of delivering explosives up to seventy miles. The device featured a time-fuse that could be calibrated depending on wind speed and the distance the balloon needed to travel to reach enemy lines.⁴

The small balloon designed by General Tada was one of many unique weapons under development at Noborito, then still in its spy movie phase. Other devices included a small unmanned tank, rocket-propelled explosives, and the “death ray,” a concentrated burst of electricity that it was hoped would obliterate any enemy soldier in its path. Each prototype was assigned a code name with the ending -go

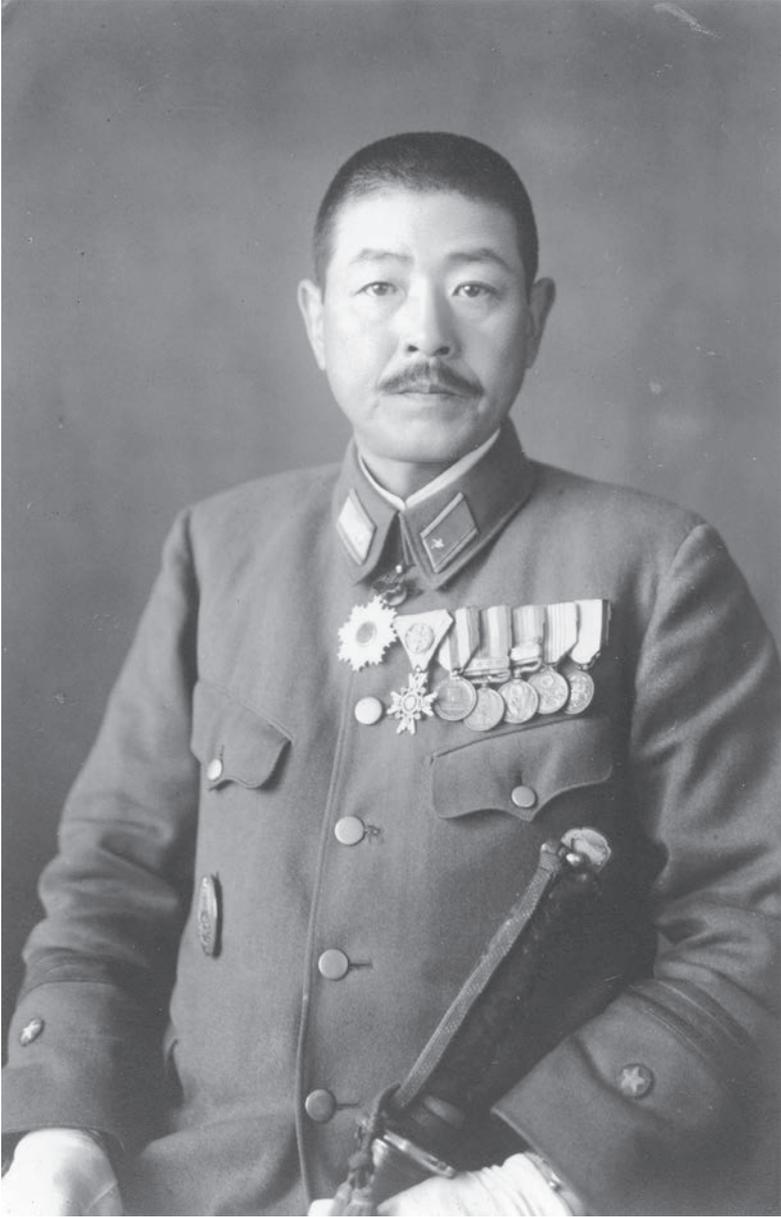


FIG. 3. Major General Sueki Kusaba, head of the Fu-go program. Bert Webber Papers, Box 2, Hoover Institution Archives, Stanford University

(a numbering suffix in Japanese). The tank was the *I-go*, the rocket the *Ro-go*. Tada's balloon project took the name *fu-go* from the first character of *fusen*, the Japanese word for "balloon."

General Kusaba, who had served under Tada in the 1930s in the original balloon program, now revived the *fu-go* project. Using the very prototypes that had been in storage for a decade, Kusaba began modifying the design for longer flights. After nearly a year of research and testing, his team came up with a design capable of remaining aloft for thirty hours at an altitude of 25,000 feet. Tests demonstrated the balloon could easily travel several hundred miles, though General Kusaba believed a range as great as two thousand miles was possible under optimum wind conditions. According to the proposal then under development, the six-meter balloon was to be inflated on the deck of a submarine and released at night within six hundred miles of the coast of the United States, a distance the balloon could cover in about ten hours. Launching the balloons in the cool nighttime temperatures would keep internal pressure fluctuations to a minimum and offered the best prospect for relatively constant altitude. Looking ahead to the program's operational phase, the Noborito technicians planned to install a time-control device on each balloon that would release a five-kilogram incendiary bomb once the vehicle had completed its flight.

By summer 1943 two submarines had been outfitted with launching equipment, and Kusaba's team had initiated the manufacture of several hundred balloons. Despite this progress, the project was canceled that August. The escalating war in the Pacific required every vessel in the Japanese fleet, and the Imperial Navy proved unwilling to dispatch any submarines on balloon missions that would only scatter minor ordnance on American soil. The finished balloons were warehoused at Noborito.

Could a balloon launched directly from Japan reach the United States? A trans-Pacific flight required a balloon with a range of at

least six thousand miles. Engineers at Noborito faced two immediate problems. First, experience with the submarine balloons suggested that such a flight would take several days, meaning the balloon would undergo severe pressure fluctuations over the course of its journey. A fixed volume of gas inside a sealed balloon would expand during the daytime as temperatures rose. The envelope would almost certainly burst unless some means for venting the gas could be devised. At night, cooling temperatures would result in contraction of the gas and loss of altitude. The balloons might fall into the ocean their first night out.

The second problem engineers identified was whether the westerly winds crossing Japan were even capable of carrying a balloon across the ocean. For answers they consulted Hidetoshi Arakawa at the Central Meteorological Observatory in Tokyo. Arakawa and his colleagues had long known of the existence of high-altitude westerlies directly above Japan. They believed these winds continued into the Western Hemisphere, though their probable flow patterns remained a mystery. In attempting to diagram the possible trajectory of winds across the Pacific, Arakawa drew on decades-old research from a pioneer of Japanese meteorology, Wasaburo Ooishi.

As a young atmospheric physicist in the 1910s, Ooishi visited universities and meteorological institutes throughout the United States and Europe, including the Lindenberg Aerological Observatory in Berlin. His travels typified the Japanese practice of the time where promising young scientists were sent abroad to learn Western scientific methods and then brought back home to prestigious university posts. Despite having his travels interrupted by World War I, Ooishi spent several years observing leading scientists who pioneered techniques for studying the upper atmosphere. He brought cases of instruments back to Japan in 1920, intent on researching upper-air wind currents.⁵

Over several days in early December 1924, under brilliantly clear

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skies with seemingly no limit to upper-air visibility, Ooishi launched a sequence of one-meter balloons from the Tateno Observatory, a small weather station northeast of Tokyo he had established immediately following his return from the West. The balloons reached 30,000 feet in about half an hour. Tracking the balloons' lateral movement with a theodolite, Ooishi calculated the wind speed at 140 knots at altitude.

This and other observations led Ooishi to a simple yet ground-breaking discovery. He had recorded comparable wind speeds before, yet they seemed to vary from week to week and month to month. Wind speeds recorded in summer, for example, rarely exceeded twenty knots, leading Ooishi to theorize that the strong winter winds were unpredictable anomalies. The Western scientific papers available to Ooishi, including the definitive study at the time by Nobel laureate Robert Millikan, all offered the same explanation—strong substratospheric winds were not uncommon but also not persistent. With his long-term observations over multiple seasons, however, Ooishi had discovered definite patterns in the relationship between upper-air features and the passage of weather fronts. From March 1923 to February 1925 he recorded 1,288 observations. Plotting seasonal wind speed and direction using these data points, he found that winter winds were markedly stronger at every altitude (especially above 25,000 feet) than during the other seasons. Far from being anomalies, the westerly winds of the upper atmosphere had great seasonal predictability.⁶

Ooishi published his findings, not in Japanese, but in Esperanto, an auxiliary language invented to allow people of different nations and native tongues to communicate. Regardless, his paper was essentially ignored by the world meteorological community. Though no one realized it at the time, Ooishi had helped lay the foundation for study of what would come to be called the jet stream, a phenomenon Western scientists would not fully understand or appreciate until after World War II.

In late 1943, after Ooishi had received the Order of Sacred Treasure and retired from the Central Meteorological Observatory, Hidetoshi Arakawa used his predecessor's charts of wind flow over Tokyo in an attempt to extrapolate wind speed and direction to the east across the Pacific. He coupled Ooishi's data on surface temperature and wind (relative to conditions at higher altitudes) with surface data from over the ocean. Following a well-established methodology that assumed a decrease in both temperature and pressure at higher altitudes, Arakawa mapped out approximate flow patterns for the different seasons. He estimated a balloon released in winter from Japan that was able to maintain an altitude of between 30,000 and 35,000 feet could reach the North American continent in thirty to one hundred hours. The strongest winds blew from November to March at speeds approaching two hundred miles per hour. Balloons released at other times of year would experience longer flight times, if they were able to cross the ocean at all. Arakawa next obtained data from weather stations in Sendai, Niigata, Wajima, Yonago, Fukuoka, Shio-no-Misaka, and Oshima, which he used to map possible transoceanic flow patterns. This information would later prove useful to Noborito in selecting launch sites for the balloons.⁷

Encouraged by Arakawa's findings, General Kusaba ordered the six-meter submarine balloons taken out of storage and outfitted with radiosondes, small devices capable of recording and transmitting data on basic atmospheric conditions. Originally designed as offensive weapons, they would now be used as weather balloons. Over a period of several months in the winter of 1943-44, a joint task force consisting of officials from Noborito and the Central Meteorological Observatory released two hundred balloons from sites up and down the east coast of Honshu, Japan's main island. Although none came close to reaching North America, many balloons remained aloft for up to thirty-six hours and sent back information that both corroborated Arakawa's findings and facilitated the creation of even more



FIG. 4. Research team from Noborito conducting launch tests at Ichinomiya in 1943. "Nishida Group," Bert Webber Papers, Box 10, Hoover Institution Archives, Stanford University

detailed wind charts. Engineers at Noborito now firmly believed that a transoceanic balloon flight was possible.

OUR RED BLOOD BURNS

Students at the Yamaguchi Girls High School gathered in the shade of a large ginko tree in the schoolyard on a hot summer day in 1944. The girls, all in their mid- to late teens, had been summoned to the yard to receive a visitor from the nearby Kokura Arsenal, an industrial weapons production compound. Like students all over Japan, the girls at Yamaguchi had already been supporting the war effort for some time. From the start of the war, classes decreased in number and eventually ceased altogether as the girls went to work sewing uniforms for soldiers stationed at a nearby infantry regiment.

As more and more men from the village left for military service, the girls filled in by working the rice fields and mining charcoal from the mountains. They undertook these strenuous labors willingly. The militaristic nature of their schools had prepared them for total allegiance to the emperor and the war. “Sacrifice yourself to serve” was a principle taught to every class.⁸

The Kokura Arsenal officer had come to Yamaguchi to recruit the girls for a special mission. They would be making a “secret weapon,” he told them, one that would fly across the ocean all the way to America.⁹ While the officer spoke, troops began setting up wooden stands in rows up and down the schoolyard, each supporting a drying board the size of a *tatami* mat (three by six feet). Told they’d be making paper, the girls had no idea what exactly that meant or how their labor would result in a flying weapon. As each student took her place at one of the drying boards, a soldier took out a saw and began cutting down the ginko tree. Its shade would hinder the drying process, the officer explained.

The conscription of the girls to the *fu-go* program followed a series of strategic decisions made by General Kusaba and the Noborito engineers. From the moment he assumed command of the balloon program, the general had grappled with the operational limitations of using balloons as intercontinental weapons. Targeted bombing of American military installations, factories, or urban areas would prove next to impossible since the balloons could not be controlled once released. Even launching them at close range from submarines would only open the vessels to immediate counterattack. Manned balloon flights were briefly considered, but quickly dismissed as impractical. The random nature of balloon flights precluded the selection of specific targets and instead forced Kusaba to consider the meager net effect of isolated attacks that in all statistical probability would occur in sparsely populated rural areas of the western United States.

The Yokosuka floatplane attack over Oregon achieved no strategic objective, only the starting of a few small, easily extinguished fires. Yet the mission demonstrated that if large-scale forest fires could be ignited the Americans would have to fight the blazes by diverting resources that otherwise might be used in the war effort. The nuisance factor alone might be worth the effort, regardless of whatever damage the balloon bombs actually caused. A single incendiary bomb, containing just a few pounds of thermite and dropped on a dry forest, could conceivably ignite a raging fire that would scorch thousands of acres. So what about a hundred incendiary bombs? A thousand? The effect of ten thousand balloons each dropping several incendiary bombs might be devastating, even if only a fraction of those bombs actually started a wildfire. “One match-stick may cause a conflagration,” wrote one Noborito technician.¹⁰

The Imperial Army estimated that only 10 percent of balloons released from Japan would reach America, with an unknown number of those conceivably failing to detonate their bombs. An effective campaign would therefore require tens of thousands of balloons, yet procuring construction materials represented a challenge for resource-poor Japan. Technical Major Teiji Takada, a procurement officer on the *fu-go* project, grasped the large number of fuses, electric components, and other hardware the program would require. He began identifying critical components with respect to whether and how they could be made from cheaper substitute materials.¹¹ For the envelope, no cheaper substance could be found than that used for every other balloon to date in the *fu-go* program—thin layers of tissue paper.

Kozo, a member of the mulberry family, is a deciduous tree native to eastern Asia with bark composed of exceptionally strong fibers. *Washi*, or Japanese paper, can be made from *kozo*, first by scraping, washing, and boiling the bark in a solution of lye. Once washed to remove all traces of lye and other impurities, the fibers are rolled

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into balls and pounded. The resulting pulp is mixed with water, scooped onto a frame, and finally pressed and dried to form sheets of lightweight yet uniformly strong paper.

The advantages of making balloon envelopes out of *washi* occurred to Noborito engineers from the very beginning of the *fu-go* program. It was cheap, easy to make, lightweight, and durable, and *kozo* trees grew in abundance all over Japan. Large sheets of handmade *washi* obtained from commercial paper companies across the country were brought to Noborito for testing. The samples varied in thickness and quality of construction, even among sheets made by the same company, which convinced the army that the eventual mass production of balloons would require standardized methods. Engineers determined that four or five layers of thin tissue paper pressed and laminated together offered the strongest composition for the balloon envelopes. After experimenting with many different glues and sealants, it was discovered that a hydrocellulose paste made from *konnyaku*, a type of Japanese potato, provided a strong, gas-proof seal between the individual sheets.

One of the Yamaguchi students, fifteen-year old Tetsuko Tanaka, described the schoolyard paper factory forty years later in a memoir of schoolgirls who worked on the project:

We covered the board with a thin layer of paste made from the *konnyaku* plant and then laid down two sheets of Japanese paper and brushed out any bubbles. When dry, a thicker layer of paste, with a slightly bluish hue, a little like the color of the sky, was evenly applied to it. That process was repeated five times. We really believed we were doing secret work, so I didn't talk about this even at home, but my clothes were covered with paste, so my family must have been able to figure out something.¹²

The army mobilized thousands of teenage girls at schools across the country when it became apparent the commercial paper factories



FIG. 5. Japanese schoolgirls at paper drying boards. “Cutting balloon paper to size,” Bert Webber Papers, Box 10, Hoover Institution Archives, Stanford University

would not meet Noborito’s order for ten thousand balloons in time for autumn and the start of the windy season. For months, the Nippon Kakokin Company, Mitsubishi Saishi, and Kokuka Rubber Company had been producing paper using standardized steel frames instead of the traditional wooden ones. The army instituted the industrial approach in order to secure paper of uniform size, thickness, and composition. Production hit a bottleneck in the time-consuming step of laminating and gluing the sheets, so the companies began shipping raw paper to schools across Japan.¹³

With the start of the autumn rains the entire operation at Yamaguchi High School had to be moved into the gymnasium, where the drying of the sheets proceeded much more slowly. Eventually the girls tried lighting charcoal in a large hibachi in a futile effort to get the paste to dry. The attempt only succeeded in making several girls sick from carbon monoxide poisoning and very nearly burning down the

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school. All across Japan, the wet autumn season and coming winter caused the army to reconsider its paper-making operation. Everything had to be moved indoors. The army consolidated its efforts by moving production facilities, including the young female laborers, to factories across Japan.

On January 2, 1945, a day after celebrating the sacred New Year's holiday with their families, the 150 members of the Yamaguchi senior class joined hundreds more from schools around the prefecture at the paper factory at Kokura Arsenal. They had boarded the train for Kokura that morning after a brief visit to a Shinto shrine and a farewell ceremony at the station where their parents and teachers waved goodbye. "You must behave like the daughter of a warrior family," one student was instructed by her grandmother.¹⁴ Fully aware the weapons compound might be targeted for bombing by American planes, the school principal had for a time resisted sending the girls to Kokura. After the students of nearby Nakamura High School were sent away in December 1944, the Yamaguchi students begged to go as well. One girl fetched a razor so they could write the principal a petition in blood.

Upon arriving in Kokura, the girls caught sight of a completed balloon, its billowing canopy much larger than they had imagined. "This was what we'd been making! It fired our determination," Tetsuko Tanaka recalled. The students lined up in formation in the blowing snow of the factory yard along with scores of male army recruits. Each girl wore a white *hachimaki* (headband) with the school emblem and the words "Student Special Attack Force." They were proud to stand next to the handsome men in uniform and know they too were serving their country. An army officer, so young that he reminded the girls of their older brothers, led them in a pledge of allegiance to the emperor and announced he would receive the spring of their nineteenth year. They would shed their youth, in other words, and pass to womanhood at the factory. Standing side by side in the snow,

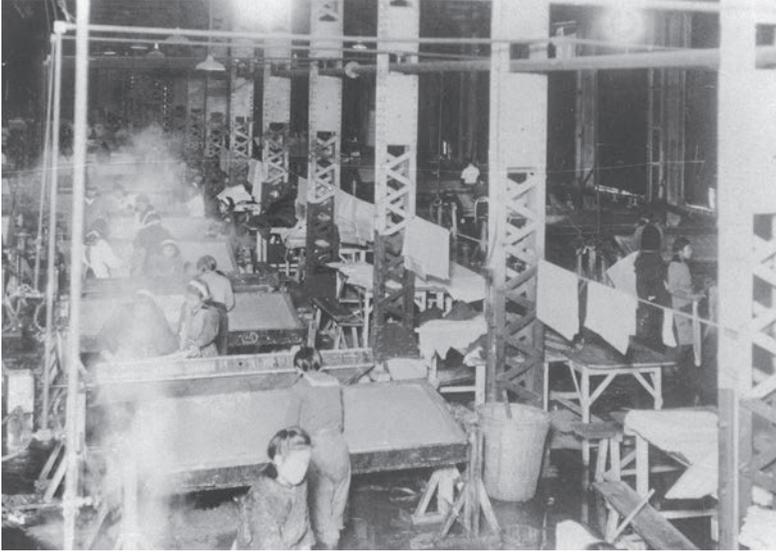


FIG. 6. “Plant of utter darkness”: Kokura Arsenal where Japanese schoolgirls manufactured paper, 1944-45. Koichi Yoshino

the young men and women proudly sang a war song called “Our Red Blood Burns.”¹⁵

The sight that greeted the girls when they walked into the Kokura factory for the first time put to rest any notion of their sunny schoolyard back home. The entire first floor was filled with countless metal drying boards and dozens of steam-drying machines that operated at temperatures approaching 160 degrees Fahrenheit. Girls operated two boards at a time, shuffling back and forth between gluing one set while the other dried. Condensation dripped continuously from the ceiling above, while the floor was covered with paste that had spilled from the boards. Prohibited from wearing shoes to prevent accidentally tearing the paper with a misstep, the girls worked ankle deep in the muck wearing only thin socks. Fungal infections were common. Long black drapes had been hung over the windows to

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maintain absolute secrecy, giving the room a gloomy, cavernous feel. The students called it the “plant of utter darkness.”¹⁶

The girls worked twelve-hour shifts in the sauna-like factory, with no breaks except to use the toilet, then trundled back to their unheated dormitory where they peeled dried *konnyaku* paste from their clothes before collapsing of exhaustion. Deprived of a lunch break during the shift, it was not uncommon for girls to slip away to the second floor, where the paste was made in large wooden barrels, and quickly sneak a bite of the powdered *konnyaku*. Dinner usually consisted of two rice balls, the occasional wilted vegetable, and miso soup. Despite the privations, the students also tried to be ordinary teenage girls. They began to loosen their headbands little by little so their hair would fall down as they walked by soldiers in the yard. They tried using toothpaste as make-up and extracted juice from *hechima*, a type of large gourd, to use as skin lotion. Lipstick was a precious commodity obtained from girls who lived near the plant.¹⁷

The sheets the girls produced, five layers of paper set with their fibers in alternating directions for added strength, were inspected for flaws by being placed atop a large light box. Small tears or areas where the sealant had been insufficiently applied showed clearly as glowing spots on the paper and were subsequently patched. After washing the paper in soda ash, water, and glycerine in order to make it pliable and prevent cracking, girls in the assembly room measured and cut the sheets into long trapezoidal panels, some six hundred of which were required for each balloon. The panels for each hemisphere were arranged over a form and taped and sewn together at the seams. Girls who worked in the assembly room were required to have closely trimmed fingernails and could not wear hairpins.

Once the two halves had been joined with a reinforced waistband seam, the completed balloon was covered with a waterproofing lacquer. For the final step, a scalloped skirt with attach points for the nineteen shroud lines was glued around the balloon just beneath the

equator. The final assembly usually occurred, not at the factory, but in large buildings around Tokyo such as the Nichigeki Music Hall and Kokugikan sumo arena. Testing of the balloons by inflating them to their full capacity required such roomy indoor spaces. The army also wished to assemble the envelopes as close as possible to the launch sites on the east coast. Transporting the balloons in their assembled state long distances only increased the risk they would be damaged in transit.¹⁸ The schoolgirls who assembled the balloons, including the students of Yamaguchi High School, greeted every successful test with cries of “Bonzai!” They knew nothing of the stratospheric winds, incendiary bombs, or even whether their creations were actually going to reach the United States. Said Tetsuko Tanaka, “We just pasted paper.”¹⁹

The Imperial General Headquarters placed such importance on the *fu-go* project that it directed the navy to begin its own balloon program in parallel with that of the army/Noborito campaign. Technical Lieutenant Commander Kiyoshi Tanaka headed the navy effort that experimented with a nine-meter envelope made of rubberized silk, what would come to be called the B-Type balloon (the army’s balloon received the designation of A-Type).²⁰

The Naval Meteorological Service analyzed data from weather balloon flights over the Pacific Ocean and concluded air temperatures at 30,000 feet would vary between 80 degrees Fahrenheit during the day and -60 degrees at night. For a hydrogen-filled balloon to survive the corresponding pressure fluctuations would require either some means for regulating its internal pressure or an envelope of exceptional strength and flexibility. The navy chose the latter approach and developed a fully sealed balloon designed to withstand more than double its expected internal maximum pressure.

Layers of lightweight *habutai* silk were pressed together and then impregnated with a thin layer of rubber. The sheets were cut into panels and pasted together with rubber cement to form a perfect

sphere. The rubberized material made the B-Type balloons strong, but also quite heavy. The initial round of tests in early 1944 showed that partially inflated balloons had almost zero lift at ground level. Even fully inflated balloons tended to bounce along the ground several times before rising, in the process risking damage to the payload or to the envelope itself. Eventually the navy refined the design so that the B-Type balloons achieved an altitude of 30,000 feet and entered the currents of strongest wind about two or three hours after launch, still a particularly slow ascent.

Transporting a full payload of bombs appeared beyond the capacity of the B-Type balloons, so the navy focused its program on gathering meteorological data from the far reaches of the eastern Pacific. Radiosondes identical to those previously used on the six-meter balloons were installed on the carriage, while another meter specially designed by the navy measured pressure inside the balloon.

Six B-Type balloons were released from Ichinomiya, a small oceanfront town in Chiba prefecture near Tokyo, in August 1944. Radiosonde transmissions from three of them terminated after only two hours, suggesting the balloons burst immediately after reaching altitude. The navy sent its remaining stock of balloons to the Fujikura Rubber Company, where technicians discovered the failure occurred at the rubber-cemented seams that began splitting apart at high internal pressures. Lieutenant Tanaka ordered all further tests suspended until the seams could be reinforced. The navy also decided to install a simple venting mechanism, a circular, spring-loaded relief valve, to meter off small volumes of gas as the balloon ascended.

By this time the navy program was close to being shut down. Imperial Headquarters had recommended the A- and B-Type programs be consolidated under army control. The supreme naval commander, Admiral Shigetaro Shimada, then under fire for a series of devastating losses including the fall of Saipan in July, was in no position to oppose the move. Not only had the B-Type program not

produced any substantive advances, but the availability of materials for the rubberized balloons had dropped off sharply as Japan's resources dwindled. With its paper-production efforts fully ramped up, Noborito assumed formal leadership of the B-Type program. Although army General Kusaba left day-to-day operational control to Lieutenant Tanaka and his original navy team, development and testing of the B-Type balloons continued for several more months without significant results.

Noborito's paper balloon measured ten meters in diameter but weighed just 152 pounds. Constructing the envelope entirely of lightweight paper meant that the device's buoyancy would not be unduly compromised by the bulk of the apparatus itself. With a volume of 19,000 cubic feet of gas, the ten-meter balloon had a lifting capacity of a thousand pounds at sea level and approximately three hundred pounds at altitude. The army engineered the balloon's dimensions based on its degree of buoyancy measured against the combined weight of the altimeters, batteries, bombs, and an altitude-control ballast system then under development that the balloon would carry.

Working with the ten-meter prototype, engineers confronted the penultimate challenge of the entire project: how to regulate internal pressure for the duration of the flight. While the navy's initial approach basically bypassed the problem by dint of the strongest possible envelope, the army sought to finesse a solution with two metal discs and a spring.

Engineers designed a pressure-relief valve to be installed on the inflation stem at the bottom of the envelope. A thin rubber gasket was glued to a steel disk seventeen inches across. A small metal tripod held in place an axial bolt and compression spring that pressed the gasket against the other metal disk and created an airtight seal. The valve's two disks burped open and permitted small volumes of gas to escape when the internal pressure of the envelope exceeded the setting of the compression spring. Not only did the design prevent the



FIG. 7. Pressure relief valve recovered in Alaska, date and location unknown. Untitled photograph, Box 43, Japanese Balloon Sightings, Record Group 499, Western Defense Command, NARA

envelope from bursting when it swelled under the constant daytime solar radiation of the upper atmosphere, but the periodic venting of the gas also kept the balloon from rising above 40,000 feet and exiting the narrow channels of strongest winds that existed at that altitude.²¹

The opposite problem occurred during nighttime when cooler temperatures would cause the balloon to descend below 30,000 feet and drop out of the wind currents. The problem would be exacerbated each successive day of the balloon's journey as more and more unrecoverable gas was released during the daytime. A system of ballast weights that could be jettisoned whenever the balloon dropped below preset minimum altitudes represented the best possible solution.

A team of engineers designed a sophisticated altitude-control

mechanism. The device not only represented the bulk of the balloon's entire payload but also included the release mechanism for the bombs themselves. Thirty-two bags of sand, each weighing between three and seven pounds, hung around the perimeter of a cast aluminum four-spoke wheel twenty-four inches in diameter. The wheel had seventy-two evenly spaced holes drilled horizontally around its outer rim, into which an equal number of blowout plugs, each containing a black powder charge, were inserted. Each sandbag was suspended by a small T-shaped flat iron bar, which in turn was held in place by a pair of adjacent blowout plugs, one under each arm of the T. A series of fuses connected all thirty-six pairs of blowout plugs (four for the incendiary bombs and the rest for sandbags) to four aneroid-barometer altimeters housed in a one-foot square box bolted atop the wheel.

An activating fuse, several feet in length and coiled around the aneroid box, was ignited at the time of the balloon's launch. The ballast mechanism would only be activated once the fuse burned through to its end and triggered a pair of spring-loaded contacts that completed the electrical circuit between the aneroids and a small 2.3-volt battery. The fuse took nearly an hour to burn, giving the balloon ample time to ascend above the aneroids' minimum threshold. The delay was necessary to avoid any accidental release of either ballast or bombs before the balloon reached altitude. Engineers worried not about the bombs falling on Japan right after takeoff (the launching facilities would be in rural areas next to the ocean) but that an early release of ballast would compromise the mission's chances, while an inadvertent release of bombs would render the entire contraption worthless.

The aneroids operated by responding to changes in atmospheric pressure. A thin disk made of a flexible, corrugated metal lay flat against a moveable bar. The disk gradually flattened out under increasing air pressure and regained its original shape with decreasing

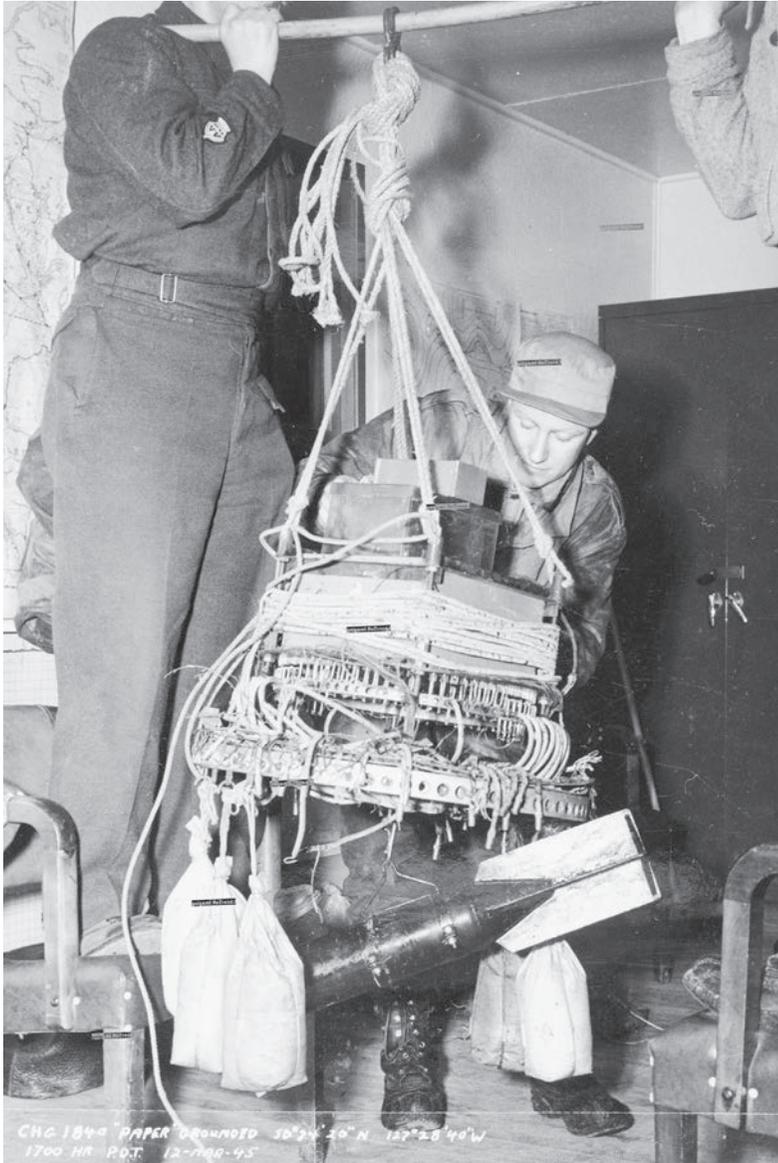


FIG. 8. Balloon chandelier with sandbags and high-explosive bomb attached, recovered near Coal Harbour, British Columbia, on 12 March 1945. "Coal Harbour," Library and Archives Canada, Department of National Defence fonds, PA-203227

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capable of dropping bombs in a timed sequence as soon as the master aneroid closed. If every set of blowout plugs fired as intended, the four incendiary bombs (sets 33 through 36) could also be dropped in sequence at any altitude in the same manner as the ballast. The last remaining projectile, an anti-personnel bomb hanging in the center of the main wheel, would be dropped when the fourth aneroid closed at its preset altitude.

At 7:29 a.m. on August 29, 1944, one of the first balloons to include the prototype ballast mechanism was released on a test flight from Ichinomiya. It did not carry bombs. The balloon instead carried a radiosonde specially designed by the Army Weather Bureau. Previous devices had alternately failed in the extreme cold of the upper atmosphere or lacked the transmitting power to consistently send signals from the farthest reaches of the Pacific. The Weather Bureau devised numerous radiosondes with dual two-watt batteries capable of transmitting for up to eighty hours in stratospheric conditions. Three radio stations operated by the army's Fifth Technical Research Institute tracked the signals.²³

The balloon ascended 20,000 feet in just half an hour and then leveled off at 26,000 feet as it entered the prevailing westerly winds. "Into the observation room, persons slipped one by one," noted Teiji Takada of Noborito Institute. Having worked toward this goal for over two years, everyone was desperate to follow the balloon's flight. Between nine and twelve hours later, just as the sun was setting, the ballast mechanism underwent three separate cycles of sandbag drops. The last cycle sent the balloon above 30,000 feet where it remained until the following evening when another four cycles commenced. Radio contact was lost for ten hours but then reestablished on the flight's third morning. Wrote Takada,

Two track observers read the degrees of the dial with their blood-shot eyes and plotted the readings on the graph to extend the

tracking curve on it. . . . Everybody fixed their eyes upon the fingers of observers on the handle of [the] dial, without moving nor whispering. In the absolute silence prevailing there, a weak boom of the radio receiver waved up and down in tone as an only sound to be heard, keeping everybody in emotional silence.²⁴

By the time radio signals ceased after just over fifty-eight total hours of flight, the balloon had jettisoned twenty-five of its thirty-six sandbags. Based on the number of bags dropped per hour of flying time, engineers believed the balloon remained aloft for another two days.

Officials at Noborito were thrilled. It was only August, well before the strongest winds of autumn and winter, and numerous test balloons released that month kept sending signals for up to eighty hours. Although their precise distance and trajectory could be monitored for only the first ten to thirty hours, that the radio signals continued for so long indicated the balloons remained in flight and were certainly capable of reaching North America.

The engineers behind the successful ballast device next designed a self-destruct mechanism. The dropping of the last bomb ignited two final fuses, one to a demolition charge on the main carriage and the other to a flash bomb cemented to the envelope above. The demolition charge, a two-pound block of picric acid encased in tin, contained a three-minute fuse and was placed atop the aneroid box. If the system worked as designed, the charge would obliterate the carriage shortly after the release of the last bomb. The balloon, now freed of its entire payload, would ascend rapidly to the upper atmosphere where the flash bomb, a simple paper pouch filled with 250 grams of magnesium powder on an eighty-two-minute fuse, would ignite the hydrogen and destroy the envelope. Just as the Doolittle Raid had shocked the Japanese by appearing seemingly from nowhere, the balloon team at Noborito was enthralled by the prospect that

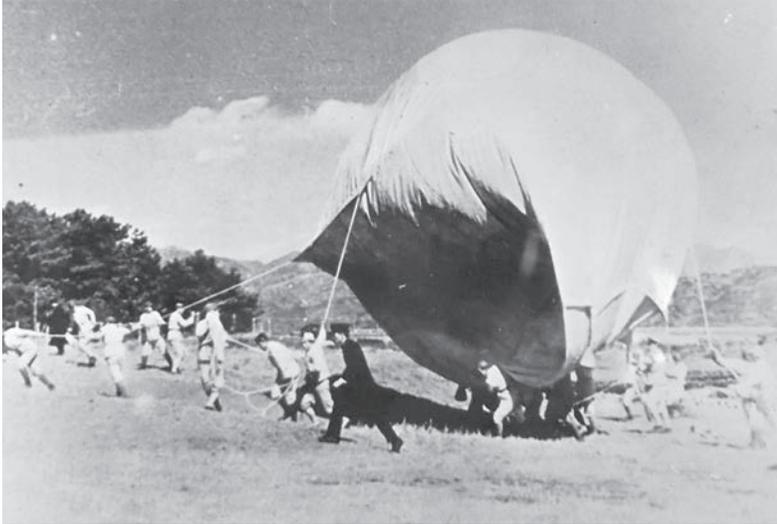


FIG. 9. Japanese launch crew training with inflated balloon, February 1944. Bert Webber Papers, Box 11, Hoover Institution Archives, Stanford University

bombs would rain down on the Americans, who would have no idea where they had come from.

Selection of the launch sites for the balloon bombs, a task that fell to the Special Balloon Regiment, an operational unit of the *fu-go* program, had to be done carefully with a few key criteria in mind. The sites had to be on the coast in the sparsely populated countryside, both for the sake of secrecy and to minimize the risk that a wayward balloon would damage infrastructure in Japan, yet they had to be easily accessible by rail to facilitate transport of the materials. The Special Balloon Regiment also consulted wind charts prepared by various meteorological agencies to determine where in the upper atmosphere the strongest currents passed over Japan.

Ichinomiya was the obvious first choice. The oceanfront village had been used extensively for testing since the revival of the balloon program in 1942, and it already featured a wireless station capable

of tracking airborne radiosondes. A battalion of seven hundred men was dispatched to Ichinomiya to set up facilities for six launching stations. The regiment selected two additional adjacent launch sites on the coast north of Tokyo. Nakoso in Fukushima prefecture had another six launching stations and six hundred men. Otsu in nearby Ibaraki prefecture was the largest of the three launch sites with nine stations, a weather unit, and fifteen hundred troops. The Otsu site also featured its own hydrogen plant, while the other two depended on tank delivery from chemical factories near Tokyo. The Special Balloon Regiment also identified potential launch sites in northern Honshu and Hokkaido, Japan's northernmost island, which were ruled out due to their proximity to Kamchatka. Imperial Headquarters wished to avoid any accidental balloon landings in the Soviet Union, a country with which Japan was not at war at the time.

Each launching pad consisted of nineteen anchor screws drilled into the ground and arranged in a circle the same diameter as the balloons. After laying out the deflated envelope within the circle and anchoring its skirt to the screws, technicians connected two high-pressure inflation hoses to the valve stem and pumped in eight thousand cubic feet of hydrogen. The envelopes were intentionally underinflated to allow room for the gas to expand at high altitudes. Men holding buckets of sand stood next to the valve ready to extinguish any flame that might (and occasionally did) occur. The steel relief valve was installed on the stem immediately following inflation.

With the ballast mechanism and bombs hanging on a nearby wooden stand, several crewmen threaded guide ropes through the hooks of the skirt, untethered the envelope from the anchor screws, and allowed the balloon to rise about forty feet off the ground. While other crewmen fastened the shroud lines to the chandelier, technicians performed a final check of the equipment. One by one, and at points directly opposite one another, the guide ropes were carefully detached from the skirt until only a few remained. The activating

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fuse was ignited as the final step before launch. The remaining guide ropes, looped through the skirt with one end attached to the ground, were then released simultaneously. Any rope that tangled and failed to slide free of the hook as the balloon ascended was quickly cut at the ground and allowed to escape with the balloon.

The entire process took between thirty minutes and an hour, depending on the presence of surface winds that made releasing the balloons more difficult. Early mornings and the period just after sunset were typically the calmest and proved the best time for launching. Even a light breeze forced the crewmen to hold the envelope much closer to the ground while others readied the carriage. In one disastrous launch test in August 1944, a sudden gust forced the inflated envelope to the ground and violently pulled the guide ropes from the hands of all who were present. An engineer visiting from Noborito described the scene:

The balloon, freed from detention in this way, left the ground swinging the flight equipment like a pendulum of a clock, after dragging it in a smoke of sand on the ground even for some tens of meters. . . . The balloon flattened and then elongated, bulged at the top and then at the bottom, continuously changing its feature.²⁵

One of the launch crew was unlucky enough to be shot and seriously wounded by a blowplug that fired when the carriage impacted the ground. The distressing episode caused launch technicians to develop an alternate procedure to be used whenever light winds were present. For this method, guide ropes slightly shorter than the shroud lines were attached to small, breakaway paper bags at the envelope's skirt. A moment after the balloon's release from ground level, the guide ropes snapped taut (while the shroud lines still had a bit of slack) and tore apart the paper bags. The momentary hitch in the balloon's ascent resulted in a gentler liftoff of the 250-pound carriage and avoided the sudden jolt that may have snapped the lines,

ripped the skirt from the balloon, or otherwise damaged some part of the apparatus.

For six weeks starting in late September, with the Navy's B-Type program still nominally active, a few final rubberized balloons were outfitted with radiosondes and released from Ichinomiya on data-gathering missions. Following the successful testing of the A-Type's ballast system, a rudimentary version of the mechanism was installed on the navy balloons. Technicians also recemented the defective seams that had caused some of the first B-Types to burst. With these improvements in place, the balloons outperformed any to date. One remained aloft for a then-record eighty-seven hours. One of this final group, B-32, was launched on the afternoon of November 2. Transmission ceased after only five hours, and radio operators assumed the balloon had somehow failed. Unbeknownst to the Japanese, however, B-32 continued flying east for nearly three days before settling gently in the Pacific some sixty-six miles off the coast of southern California.²⁶

Sailors aboard U.S.S. LCI (L) 778, an American auxiliary ship operating in those waters, observed a large, dull gray object floating in the water. Closer inspection revealed it to be a balloon, about two-thirds inflated, bobbing at an angle with lines extending down to some weight beneath the surface. In attempting to haul it aboard, the crew found it necessary to fully deflate the balloon—which they noted produced “a cooling effect” as the gas escaped—and also cut several of the suspension cords. Although the sailors would later report they believed some of the gear was lost in this process, they did manage to recover an aneroid barometer and a two-tube radio transmitter housed in a small wooden box.

“Balloon at first thought to be merely some special type of meteorological equip[ment],” noted a confidential telegram from the Eleventh Naval District in San Diego to the director of Naval Intelligence.²⁷ A check with the U.S. Weather Bureau provided no clues

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as to the possible origin of the balloon. A preliminary examination revealed the radio transmitter had been manufactured in Tokyo, and a small patch inside the rubber envelope contained faded, illegible Japanese characters written in pencil. The salvaged materials were crated up and shipped to the Naval Research Laboratory in Anacostia, just outside Washington, DC, where they remained unnoticed on a shelf for the next five weeks.

The San Pedro balloon (named for the nearest community to the recovery location) was the latest in a series of mysterious incidents over the previous several months. During a B-29 bombing raid of Fukuoka on August 20, pilots observed eight white, silver, or gray balloons, approximately forty to one hundred feet in diameter, at an altitude of 26,000 feet. For three days in mid-October, numerous balloons “with tails” were spotted over Okayama. One report of a sighting near Taiwan noted a “square box” hanging from ropes under the balloon. The Army Air Forces Pacific Ocean Area (AAFPOA) theorized the balloons might be anti-aircraft flak bursts, despite the fact that none that large had ever been observed before. An AAFPOA intelligence officer noted, “It is possible that high altitude balloons that have been seen are an attempt on the part of the Japanese to obtain more accurate meteorological data at high altitudes.”²⁸

A few days after the recovery of the San Pedro balloon, Army Air Force interrogators questioned a Japanese officer who had been captured in the Battle of Guam earlier that summer. The prisoner of war, unnamed in the official report, was a nineteen-year veteran of the Japanese Naval Meteorological Service and once studied physics and meteorology at Tokyo Imperial University under Sakuhei Fujiwara, head of the Japanese Weather Bureau. After Pearl Harbor, he served as chief weather officer at Truk, Saipan, and finally Guam. The prisoner told interrogators the Japanese used balloons equipped with radiosondes to monitor the position and conditions of the equatorial front with respect to both cyclones and high-velocity winds of the

upper atmosphere. They also subscribed to the Polar Front Theory of weather analysis with techniques gleaned from available Norwegian literature (a probable holdover of the Wasaburo Ooishi era). Unstated in the Army Air Force report, but certainly known to the Japanese officer, was that the huge temperature contrast between cold polar air and warmer subtropical air—in other words, the boundary between the polar and equatorial fronts—is what causes the currents of high-altitude winds and their seasonal variability.²⁹

That very same week U.S. Coast Guard personnel at Kailua, Hawaii, observed an airborne object descend into the ocean five miles out. The men dispatched to retrieve the object returned with a fragment of paper from a large balloon and an assembly of switches, fuses, and barometric contactors. The partially inflated envelope had split open as they attempted to pull it aboard, resulting in the loss of most of the envelope and damage to the payload. Weather and signal officers believed the device could be a weather balloon, though it contained no writing or markings that might identify its origin. Like its San Pedro counterpart, the Kailua balloon was shipped to Anacostia, where it aroused little attention or concern.³⁰

BALLOONS AWAY

In the predawn hours of November 3, 1944—the birthday of Japan’s former ruler, the Meiji Emperor—crewmembers at Ichinomiya readied several paper balloons for launch. The chandeliers that hung nearby contained, for the first time, a complete payload of incendiary and anti-personnel bombs. Numerous radiosonde tests the month before had not only proven the operational success of the ballast mechanism but also detected the start of the strong autumn winds. With several hundred completed balloons in stock at the three launch sites and thousands more on the way in the coming weeks, the army was ready to begin the balloon bomb offensive.

The first bomb-laden paper balloon was released at 5:00 a.m.

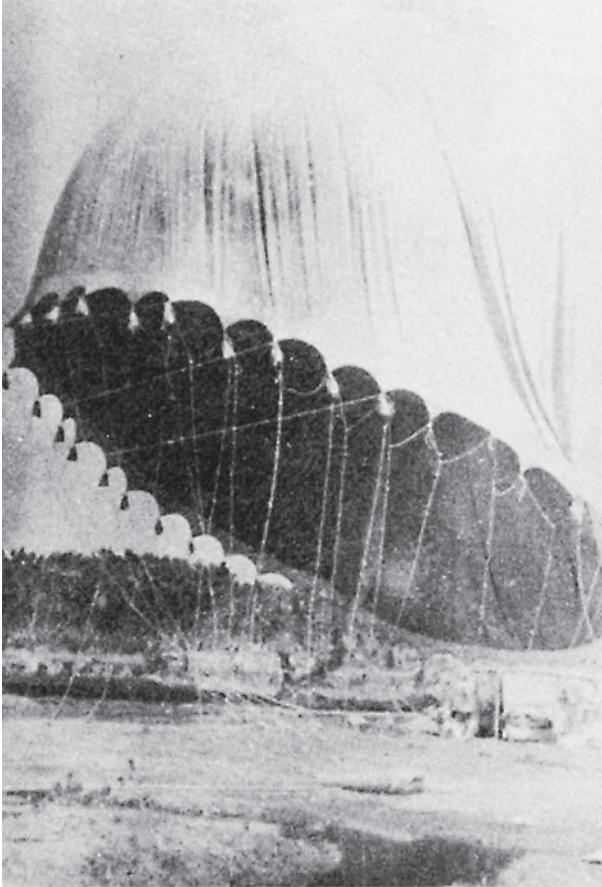


FIG. 10. *Fu-go* launch, date and location unknown. Koichi Yoshino

Soon the sky was filled with half a dozen more, the silence of their ascent broken only by the faint rustle of paper in the light morning breeze. With ropes dangling from the underinflated concave envelopes, observers compared the balloons to huge jellyfish swimming through the pale blue sky.³¹ The tranquility of the balloons' ascent belied their ultimate purpose—to infiltrate the United States, spreading fire throughout its forests and panic among its people.