

HISTORIC AMERICAN ENGINEERING RECORD

SPACE TRANSPORTATION SYSTEM, SHUTTLE CARRIER AIRCRAFT (Space Transportation System, N905NA and N911NA)

HAER No. TX-116-L

Location: Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston
Harris County
Texas

When not in active use, Shuttle Carrier Aircraft (SCA) N905NA and N911NA (hereinafter NASA 905 and NASA 911, respectively) were maintained at the National Aeronautics and Space Administration's (NASA) Dryden Flight Research Center (DFRC) at Edwards Air Force Base (AFB) in Edwards, California, located at latitude 34.949167, longitude: -117.885000. These coordinates represent Area A of DFRC, the location where the aircraft were parked; they were obtained on November 25, 2012 through Google Earth™. The coordinates' datum are North American Datum 1983.

Dates of Construction: NASA 905 was originally constructed in 1970; it was modified into a SCA in 1976. NASA 911 was originally built in 1973; it was modified into a SCA in 1988.

Builder: NASA 905 and NASA 911 were built by The Boeing Company (Boeing) as 747-123 and 747-SR-46, respectively. Each was subsequently modified by Boeing for use as a SCA.

Original Owner and Use: Before its purchase by NASA in July 1974, NASA 905 was owned and operated by American Airlines as a commercial jetliner. Prior to its purchase by NASA in April 1988, NASA 911 was owned and operated by Japan Air Lines as a commercial jetliner.

Present Owner: Both NASA 905 and NASA 911 are owned by NASA's Lyndon B. Johnson Space Center (JSC) in Houston, Texas.

Significance: NASA's Shuttle Carrier Aircraft, N905NA and N911NA, are significant in the context of the U.S. Space Shuttle Program (ca. 1969-2011). The two Boeing 747 "jumbo jets" were modified to transport the new Space Shuttle

orbiters from California to the John F. Kennedy Space Center (KSC) in Florida. They also were used in post-mission transcontinental transport of the orbiters. The comprehensive period of significance for the two SCAs is from 1977, the date of the Approach and Landing Test (ALT) Program, through September 2009, when the final ferry flight of the operational phase of the Space Shuttle Program (SSP) occurred. Specifically, the period of significance for NASA 905 is from 1977 through July 2007; for NASA 911, the period of significance is 1988 through September 2009, when it made its final SSP ferry flight.

The two SCAs were modified specifically for the task of ferrying the orbiter prototype *Enterprise*, and the five orbiter vehicles, *Columbia*, *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*. The aircraft transported the new Space Shuttle orbiters from California, to KSC in Florida.¹ The SCAs also were used for post-mission transcontinental transport when the orbiters landed at Edwards AFB in California (or White Sands Space Harbor, New Mexico, following STS-3); and for transport of the orbiters between California and Florida in support of major modifications, upgrades, and maintenance. In addition, NASA 905 was used for the ALT Program.

Description:

The two SCAs are nearly identical; like most commercial airliners, the SCAs are primarily made of aluminum. Each aircraft has approximate overall dimensions of 231'-10" in length, with a wing span of 195'-8". With the landing gear lowered, each aircraft has a rough height of 32'-1" to the top of the cockpit area, and 63'-5" to the top of the vertical stabilizer. Each SCA has a maximum gross taxi weight of 713,000 pounds.² NASA 905 has a base weight of 318,053 pounds; NASA 911 weighs 323,034 pounds. The modifications to the aircraft in support of ferry operations increased the base weight of the aircraft by about 2,800 pounds.³

The modified aircraft was designed to fly at a maximum speed of 250 knots. The SCA is powered by four Pratt & Whitney JT9D-7J gas turbine

¹ *Endeavour* was the only orbiter to be flown directly from the manufacturing/assembly site in Palmdale, California, to KSC; *Columbia*, *Challenger*, *Discovery*, and *Atlantis* were first transported overland from Palmdale to Edwards AFB prior to being flown to KSC.

² Maximum gross taxi weight is the amount of weight an aircraft can carry during preflight ground maneuvers; it includes the weight of the plane, engines, fuel, and cargo. Aviation Glossary, <http://aviationglossary.com/atog-allowable-takeoff-gross-weight-maximum-aircraft-weights/>.

³ NASA DFRC, *Shuttle Carrier Aircraft*, NASA Fact Sheets (California: Dryden Flight Research Center, 2012), <http://www.nasa.gov/centers/dryden/news/FactSheets/FS-013-DFRC.html>.

engines, installed on NASA 905 circa 1986 and NASA 911 during its modification from a jetliner to a SCA (1988-1990), which produce 48,600 pounds of thrust. The aircraft contains seven fuel tanks, including four main, one center wing, and two reserves; the fuel capacity is 47,210 gallons (316,307 pounds) of jet fuel.⁴

A variety of modifications enabled the SCA to perform its SSP functions; some of these are permanent and others are reversible. Permanent modifications included the strengthening of the aircraft's structure to allow it to support the orbiter. Extra layers of aluminum alloy skin (known as skin doublers) were added to various stress points throughout the airplane, including the locations where the orbiter support struts were located. Triple machined doublers were placed below the aft support assemblies.⁵ The SCA also has additional rib bracing and bulkheads over the length of the fuselage. Some of the skin on the horizontal stabilizer was replaced with heavier gage skin panels, and tip fin attach fittings were installed.⁶ Furthermore, because the SCA was tail heavy with the shuttle on top, 1,700 pounds of pig iron were "permanently bolted to the forward cabin on the main deck in front of the first class seats" to balance the SCA when it was carrying the orbiter.⁷ Near the tail of the aircraft, the internal structure was strengthened with bracket supports.⁸

Two of the structural modifications made to the SCAs were reversible. One of these was the installation of stabilizer tip fins and struts, one on each end of the standard horizontal stabilizer, to enhance directional stability. These vertical tip fins measure 20'-10" in height and 9'-7" in length, and are comprised of an aluminum alloy. The other reversible structural modification was the orbiter support assemblies, one near the forward end and two just behind the wings of the aircraft. The forward support assembly consisted of two 8'-6" long tubes, which allowed the orbiter to be mounted at a three-degree angle-of-attack to reduce drag

⁴ Curry, "Shuttle Carrier Aircraft."

⁵ Rockwell International, "Shuttle Carrier Aircraft ALT Design Certification Review, Volume II," slide presentation, November 5, 1976, 14 and 33, University Archives and JSC History Collection, Alfred R. Neumann Library, University of Houston-Clear Lake, Texas; Boeing, *Boeing 747 Shuttle Carrier Aircraft Illustrated Modifications* (Seattle: Boeing, 1976), 2.0-1 through 2.0-10, on file, Johnson Space Center History Office; Henry Taylor, interview by Jennifer Ross-Nazzal, *NASA STS Recordation Oral History Project*, August 26, 2011, 29, http://www.jsc.nasa.gov/history/oral_histories/STS-R/TaylorHT/TaylorHT_8-26-11.htm.

⁶ Rockwell International, "Shuttle Carrier Aircraft, Volume II," 14 and 33; Boeing, *Shuttle Carrier Aircraft*, 2.0-3 through 2.0-6.

⁷ Rick Brewer, interview by Christian Gelzer, NASA DFRC, April 11, 2011, 6, transcript provided by Jennifer Ross-Nazzal, Johnson Space Center History Office.

⁸ Rockwell International, "Shuttle Carrier Aircraft, Volume II," 33; Boeing, *Shuttle Carrier Aircraft*, 2.0-13, 2.0-14.

during ferry flights. The two aft support assemblies were each comprised of a 4'-6" long vertical strut and a 12' long drag strut. In addition, the right aft support assembly contained a 4.8' side strut and the left aft support assembly was fitted with a dual non-load-bearing adjustable side snubber.⁹

Various aircraft systems also received permanent modifications. These included the installation of sideslip sensors, additional circuit breakers, a portable oxygen cylinder, horizontal stabilizer static dischargers, a horizontal stabilizer trim bias, and an anticollision light, as well as the relocation and addition of ultrahigh frequency antennas and the retrofitting of the elevator feel computer linkage.¹⁰ Redundant power supplies and cabling also were added, primarily to power orbiter fluid system heaters and water coolant loop pumps during ferry operations.¹¹

Internally, all of the standard internal furnishings, seats, overhead bins, etc., to the aft of the forward doors were removed. Sixteen seats, eight on each side of the center aisle, were retained on the main deck for transport of support personnel. The front four seats on each side were arranged around a table, with two seats facing forward and two facing aft. Behind the seats, centered along the width of the aircraft, was a spiral staircase that led to the upper level flight deck. The flight deck retained most of its original analog displays and dials; however, new controls and displays were added to monitor new features to the aircraft systems. The front of the cockpit also had six windows, three on each side of the SCA's centerline. In addition, the three original seats were retained in the flight deck, as well as the original commode for the flight crew.¹²

At the time of documentation, both SCAs were painted white, with a blue stripe on each side along the window level of the main deck; within the blue stripe near the tail on both sides was the aircraft's registration number. In addition, a stylized NASA logo and United States flag adorned each side of the vertical stabilizer.¹³

⁹ Rockwell International, "Shuttle Carrier Aircraft, Volume II," 33; Dennis R. Jenkins, *Space Shuttle, the History of the National Space Transportation System, The First 100 Missions* (Cape Canaveral, Florida: Specialty Press), 2001, 197.

¹⁰ Rockwell International, "Shuttle Carrier Aircraft, Volume II," 56.

¹¹ Donald L. McCormack, interview by Jennifer Ross-Nazzal, *NASA STS Recordation Oral History Project*, March 24, 2011, http://www.jsc.nasa.gov/history/oral_histories/STS-R/McCormackDL/McCormackDL_3-24-11.htm. The SCA provided power to the orbiter during the ferry mission. If the orbiter lost power, some of the circulation systems and coolant loops became affected, Taylor, interview, 9.

¹² Brewer, interview, 6.

¹³ Prior to 1995, both SCAs featured the NASA "worm logo" on both sides of their vertical stabilizer.

Also at the time of documentation, there were two primary features that distinguished one SCA from the other. The first is the number of upper-deck windows on the sides of the aircraft near the forward support strut for the orbiter; NASA 911 has five windows on each side and NASA 905 has only two. The second difference was the vinyl decals applied to NASA 905 in 2012. On each side of NASA 905, to the aft of the forward door and above the main deck windows, was a series of images depicting how many times the aircraft carried each of the orbiters (*Enterprise*, *Columbia*, *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*) and the Phantom Ray; these were applied in March 2012. The second set of decals was located directly below the cockpit windows on each side of NASA 905; it depicted the names of the SCA pilots and flight engineers who participated in the final ferry flights of the orbiters.¹⁴

History:

Originally, the Space Shuttle orbiter was designed with air-breathing engines that would be used to both carry the vehicle into orbit and return the vehicle from space; additionally, the engines could be used to ferry the orbiter from one location to another. However, studies revealed these engines caused weight problems in the design. As a result, engineers began to study alternative modes of transporting the orbiter from a potential remote landing site to KSC.¹⁵

In 1973, NASA was considering both the C-5A cargo aircraft, manufactured by Lockheed,¹⁶ and the Boeing 747 “jumbo jet” as potential vehicles to ferry the orbiter. In August 1973, NASA’s DFRC awarded a \$56,000 contract to Boeing to study the feasibility of using the 747 to ferry the orbiter. The contract was the result of an unsolicited proposal submitted by Boeing. The objective of the sixty-day study was to define operational requirements, performance, cost, schedules and preliminary systems design for such a carrier aircraft.¹⁷ In October 1973, Lockheed was awarded a contract that covered wind tunnel tests simulating the use of the C-5A as a ferry aircraft. The tests of a scale model of the orbiter

¹⁴ Alan Brown, “New Logos on NASA 905 Depict Ferry Flight History,” April 5, 2012, http://www.nasa.gov/centers/dryden/Features/sca_905_logos.html. NASA 911 had, by this time, been retired from service. Brewer, interview, 15.

¹⁵ William G. Register, “747 Air Carriage of the Space Shuttle Orbiter,” in *Proceedings of the Twelfth Space Congress, Cocoa Beach, Florida, April 9-11, 1975* (Canaveral Council of Technical Societies, 1975), 1-1 through 1-3. KSC was chosen as the primary launch site for the Space Shuttle on April 14, 1972. Jenkins, *Space Shuttle*, 155. As early as October 1969, it was assumed that KSC also would be the primary landing site of the Space Shuttle. “12 Seek Space Shuttle Control Systems Study,” *Marshall Star*, October 22, 1969, 4.

¹⁶ The original version of the C-5A was manufactured by Lockheed between 1968 and 1973. This large military transport aircraft, which featured a heavy airlift capacity, was used primarily by the United States Air Force.

¹⁷ “Boeing Gets Contract for Shuttle Ferry,” *X-Press*, August 3, 1973, 2.

mounted atop a scale model of the C-5A were conducted in Lockheed's Low Speed Tunnel in Burbank, California. The objectives were to determine if the plan was technically feasible, and if so, to determine the optimum location for positioning the orbiter on the C-5A.¹⁸

Test results demonstrated that the 747 had several advantages over the C-5A. The 747 was shown to be safer, and to be capable of a nonstop transcontinental flight without the need for refueling. Additionally, it could use shorter runways, and had a longer structural life. As a result, by June 1974, NASA definitively replaced its earlier plans to install six air-breathing engines on the orbiter for ferry flights in favor of using a Boeing 747 to transport the orbiter. Following the June 1974 request of authorization made by Dr. Christopher Kraft, director of NASA's JSC, NASA's Space Shuttle Program Office approved the purchase of a Boeing 747 airplane for use as the SCA.¹⁹

On July 18, 1974, NASA purchased a used Boeing 747-123 jetliner from American Airlines for approximately \$15.6 million. At the time of purchase, the aircraft had logged about 9,000 flight hours. It was given the registration number N905NA.²⁰ Before being modified, the aircraft was initially used as part of a DFRC study of trailing wake vortices; this research was not directly connected to the SSP.²¹ Subsequently, the Boeing 747 was used in a shuttle program-related simulated separation maneuver test.

On August 2, 1976, modifications were started by Boeing at their production facilities near Everett, Washington. Work under this \$30 million contract was completed in December. Under a separate contract, the four original Pratt and Whitney JT9D-3A engines were converted to JT9D-7AHW engines to increase their power.²² For the ALT Program, a flight crew escape system was installed. It consisted of an exit tunnel extending from the flight deck to a hatch in the bottom of the fuselage.²³

¹⁸ "Shuttle Ferry Wind Tunnel Tests Slated," *X-Press*, October 26, 1973, 4.

¹⁹ "747 to be Used for Orbiter Transport," *X-Press*, June 21, 1974, 2.

²⁰ T.A. Heppenheimer, *History of the Space Shuttle*, vol. 2, *Development of the Space Shuttle, 1972-1981* (Washington, DC: Smithsonian Institution Press, 2002), 94.

²¹ Jenkins, *Space Shuttle*, 196.

²² Jenkins, *Space Shuttle*, 197. The Pratt & Whitney JT9D engine was a large commercial turbo fan engine initially used on Boeing's 747-100. The JT9D-7AHW engines were replaced circa 1996, as noted in the description section.

²³ This system was removed from NASA 905 following the completion of the ALT Program. Curry, "Shuttle Carrier Aircraft."

In January 1977, the modified SCA was flown to Edwards AFB for use with the orbiter prototype *Enterprise* in the ALT Program, conducted at DFRC between February and October 1977. Prior to the actual test flights, wind tunnel tests in support of the ALT program were carried out at DFRC as well as NASA's Ames Research Center at Moffett Field, California.²⁴ The ALT Program consisted of a series of eight captive and five free-flight tests, with the orbiter mounted atop the SCA. The initial eight captive tests verified the aerodynamics and handling of the orbiter/SCA combination and the orbiter systems. The free-flight tests "allowed the pilots and engineers to learn how the shuttle handled during low-speed flight and simulated how it would land at the end of an orbital mission."²⁵

NASA selected two, two-man orbiter crews for the ALT Program: Fred W. Haise, Jr. (Commander) and C. Gordon Fullerton (Pilot), and Joe H. Engle (Commander) and Richard H. Truly (Pilot). Crewmembers for the SCA included pilots Fitzhugh I. Fulton, Jr. and Thomas C. McMurtry, as well as flight engineers Victor W. Horton, Louis E. Guidry, Jr., William R. Young, and Vincent A. Alvarez.²⁶

The first phase of the ALT program entailed three high speed taxi tests, conducted in February 1977 at the main concrete runway at Edwards AFB (Runway 04/22). These tests proved that the SCA, mated to *Enterprise*, could steer and brake with the orbiter mounted on top of the airframe.²⁷ Two unmanned "captive-inert" tests followed. The goal of the last two test flights was to conduct the maneuvers of an air launch. Next, three "captive-active" tests featuring two-person crews were performed on June 18, June 28, and July 26, 1977. During these tests, the orbiter was piloted and powered up while attached to the SCA to check how the *Enterprise* would perform in the air.²⁸ The final phase of testing marked the first free flight of the orbiter. Five test free-flights were conducted between August 12 and October 26, 1977. The first three free tests were flown with the tail cone (fairing) on the orbiter; the fourth and fifth free flights were made

²⁴ "Shuttle Begins Wind Tunnel Tests," *X-Press*, June 20, 1975, 3.

²⁵ Lisa Tidwell, "Practice Makes Perfect. This Year Marks the 25th Anniversary of Shuttle's Free-Flight Tests," *Space Center Roundup*, October 2002, 6.

²⁶ Peter Merlin, "Proving Grounds. Enterprise Validated Shuttle Concepts," *The Dryden X-Press*, September 2011, 6-7.

²⁷ *Wings in Orbit: Scientific and Engineering Legacies of the Space Shuttle, 1971-2010*, ed. Wayne Hale (Washington, DC: US Printing Office, 2010), Appendix, 518.

²⁸ Heppenheimer, *Development of the Space Shuttle*, 121.

with dummy engines in an effort to replicate actual flight conditions.²⁹ Overall, the ALT program was successful in providing both operational experience as well as “benchmarking data for the flight simulators that were the working tools of day-to-day astronaut training.”³⁰

Following completion of the ALT Program, NASA 905 ferried *Enterprise* to the George C. Marshall Space Flight Center (MSFC) in Huntsville, Alabama, for a series of vertical ground vibration tests, which began in March 1978. On March 20, 1979, the SCA began a four-leg ferry flight to deliver the newly assembled *Columbia* to KSC. Subsequently, the SCA moved *Enterprise* from MSFC to KSC where, from May through July 1979, NASA used the orbiter prototype to verify the correct locations of maintenance platforms, and to check crew escape procedures.³¹ Later that year, the SCA flew *Enterprise* to California, where selected parts, including most of the cockpit instrumentation and consoles, the control sticks, and most of the avionics, were removed and refurbished in October 1979, for use on later orbiters.

The next use of the SCA came in April 1981 when NASA 905 returned *Columbia* to KSC following the STS-1 landing at Edwards AFB. Early in the SSP, Edwards AFB was the preferred landing site due to more stable weather conditions, as well as the choice of concrete and dry lakebed runways. Thus, the first nine flights of the SSP ended with a landing at Edwards AFB, with the exception of STS-3, which landed in New Mexico; the orbiter was subsequently carried to KSC with the SCA.

Upon the roll-out of *Challenger*, NASA 905 ferried her to KSC on a two-leg journey, flown on July 4-5, 1982. In 1983, the American Airlines markings in red, blue and silver were replaced when NASA repainted the SCA to its current white and blue. Subsequently, NASA 905 ferried *Enterprise* around the world for air shows, including the Paris Air Show in May and June 1983. Later that year, between November 6 and 9, NASA 905 carried the new orbiter *Discovery* to KSC.

In early 1984, DFRC conducted a series of inflight refueling tests to evaluate the process for application to the SCA. Two tankers, a KC-135 and a KC-10, handled the refueling of the SCA. Center personnel mounted the *Enterprise* atop NASA 905 in the mate-demate device (MDD) for six

²⁹ Merlin, “Proving Grounds,” 7.

³⁰ Heppenheimer, *Development of the Space Shuttle*, 121.

³¹ Jenkins, *Space Shuttle*, 216.

of the nine test flights. Both the *Enterprise* and SCA were instrumented with pressure sensors and accelerometers to evaluate structural effects of the refueling.³² Later that year, the SCA also transported *Enterprise* to the 1984 World's Fair in New Orleans, Louisiana.³³

By 1984, the Shuttle Landing Facility (SLF) at KSC became the primary orbiter landing site; the first landing at KSC was at the end of mission STS-41B, on February 11, 1984. Although this reduced the need for post-mission ferry flights, ten additional landings were made at Edwards AFB prior to the *Challenger* accident in January 1986, particularly after *Discovery* blew a tire upon landing at KSC following STS-23 (April 19, 1985) prompting NASA to return to using Edwards AFB as the primary landing site. NASA 905 also completed two ferry flights (January 1984 and July 1985) in support of *Columbia*'s first modification period, which took place in California.

The year 1985 marked several milestones in the career of NASA 905. In April, she delivered the new orbiter *Atlantis* to KSC, and in July, she returned *Columbia* from California following more than one year of modifications at Palmdale.³⁴ Later, in September 1985, the SCA moved *Enterprise* to KSC for display. On November 18, 1985, *Enterprise* became the property of the Smithsonian's National Air and Space Museum; the SCA ferried *Enterprise* to her new home in Washington, DC.

In the wake of the 1986 *Challenger* accident, the Rogers Commission recommended that increasing the ferry capacity would enhance reliability of ferry operations and would eliminate a "single point failure from the program."³⁵ In accordance, in February 1988, NASA announced plans to acquire a second 747 to serve as backup to NASA 905.³⁶ A surplus Japan Air Lines domestic passenger aircraft with about 32,000 hours of flight time was acquired for NASA by Boeing in April 1988. Boeing began modifications to the aircraft in 1988, at the Boeing Military Airplanes manufacturing facility in Wichita, Kansas, under a \$55 million contract,

³² "Inflight Refueling Tests for Shuttle Ferry Flights," *X-Press*, February 3, 1984, 3-4.

³³ Tidwell, "Practice makes perfect," 6.

³⁴ NASA 905 delivered *Columbia* to California on January 27, 1984, following a two-day, two-leg ferry flight.

³⁵ Barbara Schwartz, "NASA Announces Delivery of Second Shuttle Carrier Aircraft," NASA News Release, November 16, 1990, accessed at http://www.nasa.gov/centers/johnson/pdf/83142main_1990.pdf; Jeff Carr, "Ferry Fleet Doubles in Size," *Space News Roundup*, November 16, 1990, 1 and 4.

³⁶ Jenkins, *Space Shuttle*, 198.

which included the cost of purchase.³⁷ After the structural work was completed, the aircraft was delivered to Chrysler Technologies in Waco, Texas, for painting.³⁸ NASA 911 was added to the NASA fleet on November 20, 1990, and for her maiden flight in May 1991, she delivered the new orbiter *Endeavour* (OV-105) to KSC.³⁹

Between August 1991 and March 2001, the two SCAs ferried *Columbia*, *Discovery*, *Atlantis*, and *Endeavour* between KSC and Palmdale, California for major modifications and maintenance, referred to as Orbiter Maintenance Down Periods (OMDPs) and Orbiter Major Modifications (OMMs). *Columbia* made six transcontinental trips aboard both NASA 905 (February 7-9, 1992; October 8-11, 1994; April 11-14, 1995; September 24-25, 1999; and March 1-5, 2001) and NASA 911 (August 9-13, 1991). Both SCAs transported *Discovery* for her OMDP; NASA 905 left KSC on September 27, 1995 and delivered the orbiter to Palmdale the following day, while NASA 911 returned *Discovery* to KSC on a four-leg⁴⁰ ferry flight made June 25-29, 1996. NASA 911 ferried *Atlantis* to Palmdale for two OMDPs in October 1992, and November 1997, and returned her to KSC in May 1994; the other return of *Atlantis* to KSC was made by NASA 905 in September 1998. *Endeavour* underwent one OMDP at the Palmdale plant. She was carried to California atop NASA 911 on July 30, 1996, and returned to KSC by NASA 905 in March 25-27, 1997.

Notably, in 2001, a unique event in the history of the SSP took place in the form of simultaneous ferry missions. As related by Donald McCormack, NASA Ferry Operations manager, *Columbia* was at Palmdale for maintenance, and scheduled to be ferried back to KSC in late February using NASA 905, when *Atlantis* concluded her STS-98 mission with a landing at Edwards AFB on February 20. Since *Atlantis* would be flown again sooner than *Columbia*, NASA decided that the *Columbia* ferry mission could not interfere with the *Atlantis* ferry, and neither ferry flight could interfere with the launch of the STS-102 (*Discovery*) mission, scheduled for March 8. Subsequently, two independent ferry missions were accomplished, with *Columbia* using NASA 905 and *Atlantis* atop

³⁷ Jeffrey E. Carr, "NASA Buys Second Shuttle Carrier Aircraft," NASA News Release, August 10, 1988, http://www.nasa.gov/centers/johnson/pdf/83140main_1988.pdf.

³⁸ Schwartz, "Second Shuttle Carrier Aircraft."

³⁹ The maiden ferry flight crew for NASA 911 included Arthur "Ace" Beall, Dave Mumme, Larry LaRose, Henry Taylor, A.J. Roy, Skip Guidry, and Bud Meins. "Endeavour takes bow in Houston," *Space News Roundup*, May 10, 1991, 1 and 4.

⁴⁰ A leg is the distance traveled between stops for fueling or other purposes.

NASA 911. Both *Atlantis* and *Columbia* arrived at their destination on March 4; *Atlantis* went to the KSC SLF and *Columbia* went to the skid strip at Cape Canaveral Air Force Station. Following the demating of *Atlantis*, *Columbia* was moved to the SLF on March 5.⁴¹

For cost-saving reasons, beginning in September 2002, NASA relocated the orbiter overhaul and upgrade operations from Palmdale to KSC; therefore, the SCAs were no longer required to carry the vehicles between Florida and California for maintenance. However, five missions between August 2005 and September 2009 required a landing at Edwards AFB. NASA 905 returned the orbiters from two of these flights to KSC; its ferry flight of *Atlantis* from July 1-3, 2007, was NASA 905's final flight in support of the operational phase of the SSP. NASA 911 returned the other three. Its final ferry flight in support of the SSP's operational phase was carrying *Discovery* from Edwards AFB to KSC from September 19-21, 2009.

On December 13, 2010, NASA 905 carried the Phantom Ray, a 36'-long unmanned airborne system manufactured by Boeing Integrated Defense Systems, during a 50-minute test flight at Lambert International Airport in St. Louis, Missouri. This marked the first time in the SCA's thirty-three-year history that an aircraft other than the space shuttle had flown on the SCA. The following day, NASA 905 transported the Phantom Ray from St. Louis to Edwards AFB.⁴² On August 2, 2011, the two SCAs flew in formation for the first time, a historic event that occurred over the Edwards AFB test range. NASA 911 was on a pilot proficiency flight while NASA 905 was on a functional check flight following maintenance operations.⁴³

⁴¹ McCormack, interview, 19-20.

⁴² This test flight was in preparation for its transport to DFRC, on top of NASA 905, where the Phantom Ray made its first flight, which lasted seventeen minutes, on April 27, 2011. The SCA flights with Phantom Ray were conducted under a Boeing-funded, commercial Space Act Agreement with NASA. The Phantom Ray and special adapter weight approximately 30,000 pounds together. Boeing, "Boeing Phantom Ray Takes a Ride on NASA's Shuttle Carrier Aircraft," December 13, 2010, accessed at <http://boeing.mediaroom.com/index.php?s=43&item=1559>; Brian Heater, "Boeing's Phantom Ray soars like a terrifying, unmanned eagle," posted May 3, 2011, accessed at <http://www.engadget.com/2011/05/03/boeings-phantom-ray-soars-like-a-terrifying-unmanned-eagle/>; Chris Haddox (Boeing), "Shuttle Carrier Aircraft and Phantom Ray make tandem flight," No date, accessed at http://www.boeing.com/Features/2010/12/bds_phantom_ray_12_10_10.html.

⁴³ Robert Z. Pearlman, "New Boarding: Inside NASA's Boeing 747 Shuttle Carrier Aircraft," April 13, 2012, accessed at <http://www.space.com/15266-nasa-shuttle-carrier-aircraft-explained.html>.

NASA 911 made its final flight on February 8, 2012. The twenty-minute flight began at DFRC and ended at the Dryden Aircraft Operations Facility located adjacent to Air Force Plant 42 in Palmdale, California.⁴⁴ At this time, “it had amassed 33,004 flight hours over its 38-year career, including 386 flights as a NASA shuttle carrier aircraft, 66 of which were ferry flights with a space shuttle mounted atop the fuselage.”⁴⁵

Between April and September 2012, NASA 905’s final service to the Space Shuttle Program was the transport of *Enterprise*, *Discovery*, and *Endeavour* for delivery to airports near their recipient museums. On April 17, 2012, the SCA carried *Discovery* from KSC to Dulles International Airport in Chantilly, Virginia, for display at the Smithsonian Institution National Air and Space Museum’s Udvar-Hazy Center. After the delivery of *Discovery*, the SCA ferried *Enterprise* to JFK International Airport in New York City, on April 27, 2012, for its display at the Intrepid Sea, Air and Space Museum.⁴⁶

The last ferry flight of NASA 905 was the transport of *Endeavour* from KSC to Los Angeles, California. The SCA left KSC on September 17, 2012, and made an overnight stop at Ellington Field in Houston near JSC. The second leg ended at Biggs Army Airfield at El Paso, Texas for refueling and flight crew change; the third leg ended at Edwards AFB, where the orbiter/SCA combo overnighted. The following day, September 21, the SCA, flown by pilots Jeff Moultrie and Bill Rieke, along with flight engineers Henry Taylor, Larry LaRose, and Gary Ash, touched down at Los Angeles International Airport at 12:51 PM. This last leg took 4 hours and 34 minutes, during which time the aircraft made low-level flybys over numerous California cities and landmarks.⁴⁷

After all the orbiters were delivered, NASA’s plans called for both SCAs to be transferred to DFRC’s Stratospheric Observatory for Infrared

⁴⁴ Yvette Smith, ed., “World’s Greatest Piggyback Ride,” April 19, 2012, accessed at http://www.nasa.gov/topics/nasalife/features/shuttle_museum.html.

⁴⁵ Curry, “Shuttle Carrier Aircraft.”

⁴⁶ *Enterprise* was barged by way of the Hudson River from JFK International Airport to the Intrepid Sea, Air and Space Museum. To secure *Enterprise* to the barge, the pedestals from NASA 911’s aft mounting struts, removed by NASA technicians, were used. Robert Z. Pearlman, “NASA Space Shuttle Carrying Jumbo Jet Retires After One Last Flight,” February 13, 2012, accessed at <http://www.space.com/14555-space-shuttle-piggyback-jumbo-jet-retired.html>.

⁴⁷ NASA DFRC, “Endeavour Ferry Flight Status,” September 21, 2012, accessed at http://www.nasa.gov/centers/dryden/status_reports/SCA_Endavour_status_09_12.html.

Astronomy (SOFIA) Program; the SOFIA Program wanted the engines as spares, so the SCAs “probably won’t fly anymore.”⁴⁸

Function:

The SCAs primary function was to ferry the Space Shuttle orbiters from one location to another. The SCAs delivered the newly assembled orbiters to KSC to begin their operational service. NASA 905 delivered four of the five orbiters, *Columbia* (March 1979), *Challenger* (July 1982), *Discovery* (November 1983), and *Atlantis* (April 1985); NASA 911 delivered *Endeavour* (May 1991). Between April 1981 (STS-1) and July 2011 (STS-135), the SCAs completed fifty-five post-mission ferry flights following an orbiter’s landing at Edwards AFB or White Sands Space Harbor. In addition to the post-mission flights and initial deliveries, between 1985 and 2001, the SCAs transported the orbiters between KSC and Palmdale, for eight modification periods (sixteen one-way ferry flights).

Flight Procedures

In order to carry the orbiter from one place to another, the vehicle had to be attached to the SCA. This task was completed using one of two MDD structures (one at DFRC and one at KSC), an Orbiter Lifting Frame (at Palmdale), or, if necessary, stiff-legged derricks. First, a tail cone to reduce aerodynamic drag was attached to the orbiter’s base heat shield at eight attach points; this took two to three shifts to accomplish. After the orbiter was raised about fifty feet, the SCA was towed underneath, and the orbiter was lowered into position and attached at the two aft and one forward points. These three attach locations were the same as those used when the orbiter was mated to the ET. The mate process typically took about twelve hours.⁴⁹

The SCA was required to fly only during daylight hours. Chief Flight Engineer, Henry Taylor, noted that the SCA was allowed to take off up to twenty minutes before sunrise, and had to land no later than twenty minutes after sunset. The flight path was determined mostly by the weather, and generally was not the same for each ferry operation. The

⁴⁸ Taylor, interview, 16-17. SOFIA uses a highly modified Boeing 747SP aircraft as a platform for the 100”-diameter, 19-ton reflecting telescope, which is mounted in the rear fuselage. SOFIA is the world’s largest airborne astronomical observatory. Pearlman, “NASA Space Shuttle.”

⁴⁹ McCormack, interview, 2-4. For post-mission ferry flights, the orbiter typically was ready to be ferried within seven to nine days of landing. For additional information on the KSC MDD, see Patricia Slovinac, “Cape Canaveral Air Force Station, Launch Complex 39, Shuttle Landing Facility (John F. Kennedy Space Center),” HAER No. FL-8-11-J. Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, April 2011.

orbiter could not be flown through rain, to prevent damage to the tiles. Severe weather also was avoided. Temperature and pressure were additional constraints; the minimum temperature was 15 degrees Fahrenheit (F) and the minimum ambient pressure was 8 psia (pounds per square inch absolute). Because of these limits, the SCA generally flew low, in the range of 11,000' to 16,000'.⁵⁰ Before every flight leg, a weather briefing was conducted to determine if the flight could proceed.

The weight of the orbiter impacted the performance of the SCA; the mated SCA/orbiter could weigh no more than 710,000 pounds at takeoff.⁵¹ The typical weight range for end-of-mission ferry flights was about 195,000 to 230,000 pounds.⁵² When the orbiters were initially delivered to KSC, their estimated weights ranged from 158,289 pounds (*Columbia*) to 151,205 pounds (*Endeavour*), without the engines installed.⁵³ Following the eight major modifications performed at Palmdale, orbiter weight ranged between approximately 154,000 and 161,000 pounds. The heaviest orbiter ever ferried was *Discovery* after STS-114; it carried a multi-purpose logistics module in the payload bay, and weighed almost 228,000 pounds. To help balance the SCA for ferry flights, 7,000 pounds of pea gravel were added; the pea gravel was contained in cargo containers in the lower forward cargo bay.⁵⁴

The aircraft crew for ferry flights consisted of two pilots and one or two flight engineers.⁵⁵ During the transcontinental trip between California and Florida, the SCA typically stopped several times to refuel. A heavier orbiter required at least three refueling stops, sometimes four. A refuel required only a few hours on the ground. The average fuel burn for the SCA during a ferry flight was about 5,750 gallons per hour.⁵⁶ Historically, more than twenty military bases and a few international airports located across the southern one-third of the US supported ferry operations. Military bases were used almost all the time because of their security and

⁵⁰ McCormack, interview, 6.

⁵¹ Taylor, interview, 7.

⁵² Variable orbiter weight resulted, foremost, from what was returned in the payload bay. McCormack, interview, 8.

⁵³ The SSMEs added approximately 20,000 pounds to the total empty weight of each orbiter. NASA KSC, "Orbiter Vehicles," <http://www.pao.ksc.nasa.gov/shuttle/resources/orbiters.html>.

⁵⁴ Gray Creech, "Gravel Haulers: NASA's 747 Shuttle Carriers," August 22, 2003, http://www.nasa.gov/news/special/747_Shuttle_Carriers_prt.htm.; Pete Seidl, interview by Joan Deming and Patricia Slovinac, September 18, 2006; Arvid C. Knutson, interview by Jennifer Ross-Nazzal, *Shuttle Carrier Aircraft Oral History Project*, April 13, 2012, 2.

⁵⁵ Typically, two flight engineers were required for a post-mission ferry flight; only one was needed for all other ferry flights. McCormack, interview, 6.

⁵⁶ McCormack, interview, 10, 12.

support capabilities.⁵⁷ Generally, Air Force bases were favored because they have long runways.⁵⁸

Under the most favorable conditions, with good weather and a light orbiter, the cross-country trip could be made in one day with two legs; with bad weather, it could stretch out to four days or more. Typically, a ferry flight was accomplished in three or four legs flown over a period of two to three days, with one or two rest stops. Ferry flights averaged three legs per flight; all but four ferry flights were made in two to four legs. *Columbia*, *Discovery*, and *Atlantis* each had a single five-leg ferry flight following missions STS-35, STS-42, and STS-76, respectively. The initial delivery of *Endeavour* entailed a six-leg journey.

A “pathfinder” aircraft, flown by an experienced SCA pilot, took off prior to the SCA and flew approximately 100 miles ahead. The type of aircraft used as the pathfinder varied. In the winter, there were requirements to provide a heated purge of the orbiter at overnight stopovers if the overnight temperature was expected to be below 45 degrees F for more than four hours. Therefore, specialized purge equipment was needed. In these cases, a USAF C-141 or C-17 was used as the pathfinder aircraft. When purge equipment was not needed, a NASA JSC aircraft, such as a KC-135 or a C-9, typically served as the pathfinder vehicle. The pilot in the pathfinder was in radio contact with the pilots in the SCA, providing guidance to safely navigate through challenging weather conditions.⁵⁹ The pathfinder also transported all required support equipment and the thirty to thirty-five person ferry flight team, including the ferry manager, weather officers, all the KSC support personnel, the mechanics and maintenance crew, and safety and security personnel.⁶⁰

Upon landing at a stopover, a safety assessment was performed before the flight crew could depart the SCA. This consisted of toxic vapor tests and visual inspections for damage performed by KSC personnel. In the case of an overnight stop, base security personnel set up a perimeter that was at least 200’ from the SCA. Military personnel controlled the single entry point established and monitored the restricted area.⁶¹ When the plane landed at its final destination, a safety assessment was conducted, and then

⁵⁷ Taylor, interview, 21.

⁵⁸ Larry LaRose, interview by Jennifer Ross-Nazzal, *Shuttle Carrier Aircraft Oral History Project*, April 12, 2012, 5.

⁵⁹ McCormack, interview, 8-9.

⁶⁰ Taylor, interview, 22.

⁶¹ McCormack, interview, 12.

the mated vehicle was towed to the MDD. Typically, within about sixteen hours, the orbiter was demated from the SCA.⁶²

⁶² McCormack, interview, 15.

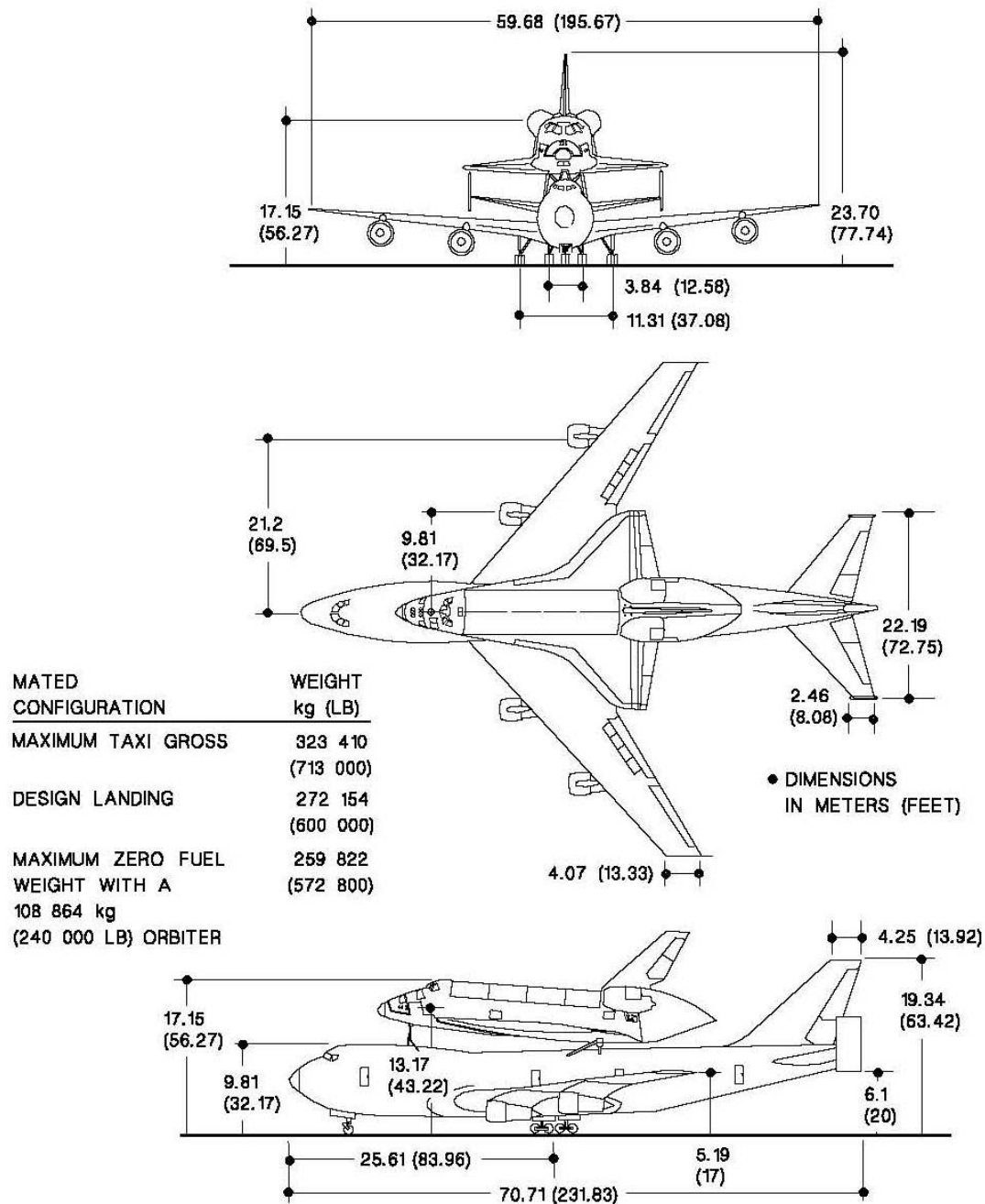


Figure 1. General dimensions of the SCA, with the orbiter vehicle.
Source: NASA, *Shuttle Operational Data Book*, Volume 4, Figure C-2.



Figure 2. View of the NASA 905 following modifications to become the first SCA,
December 23, 1976.
Source: NASA DFRC, ECN-6356.



Figure 3. View of the orbiter *Enterprise* detaching from NASA 905 during one of the Approach and Landing Test Program free flight tests, September 26, 1977.

Source: NASA DFRC, ECN77-8608,
<http://www.nasa.gov/centers/dryden/multimedia/imagegallery/ALT/index.html>.



Figure 4. View of the orbiter *Columbia* atop NASA 905, ready for departure for her initial delivery to Kennedy Space Center, March 17, 1979.
Source: NASA DFRC, ECN-10543.



Figure 5. NASA 905 landing at Kennedy Space Center with the Orbiter *Columbia* for her initial delivery, March 24, 1979.

Source: John F. Kennedy Space Center Online Multimedia Gallery, KSC-79PC-0047,
<http://mediaarchive.ksc.nasa.gov/search.cfm>.



Figure 6. NASA 905 carrying the Orbiter *Columbia* back to Kennedy Space Center following STS-2, November 30, 1981.
Source: NASA DFRC, ECN-17602.



Figure 7. NASA 905 carrying the Orbiter *Challenger* for her initial delivery to Kennedy Space Center, July 4, 1982.

Source: NASA DFRC, ECN-21131.



Figure 8. NASA 905 approaching the runway at Kennedy Space Center for the initial delivery of the Orbiter *Discovery*, March 24, 1979.

Source: John F. Kennedy Space Center Online Multimedia Gallery, KSC-83PC-766,
<http://mediaarchive.ksc.nasa.gov/search.cfm>.



Figure 9. NASA 905/*Atlantis* being towed from the Mate-Demate Device at Dryden Flight Research Center in preparation for her initial delivery to Kennedy Space Center, April 11, 1985.
Source: NASA DFRC, ECN-32885.



Figure 10. The Orbiter *Endeavour* being mated to NASA 911 in the Orbiter Lifting Frame at Palmdale for her initial delivery to Kennedy Space Center, May 1, 1991.

Source: John F. Kennedy Space Center Online Multimedia Gallery, KSC-2012-4807,
<http://mediaarchive.ksc.nasa.gov/search.cfm>.



Figure 11. View of the orbiter *Discovery* being attached to NASA 911 for the final post-mission ferry flight of the Space Shuttle Program, September 18, 2009.

Source: NASA DFRC, ED09-0253-100,
<http://www.nasa.gov/centers/dryden/multimedia/imagegallery/STS-128/ED09-0253-100.html>.



Figure 12. NASA 905 carries the Phantom Ray during a test flight over St. Louis,
December 13, 2010.

Source: NASA, http://www.boeing.com/Features/2010/12/bds_phantom_ray_12_10_10.html.



Figure 13. NASA 911 (front) and NASA 905 (rear) flying in formation over Southern California within the Edwards Air Force Base Test Range, August 2, 2011.

Source: NASA DFRC, ED11-0237-25,
<http://www.nasa.gov/centers/dryden/multimedia/imagegallery/SCA/index.html#>.



Figure 14. SCA 905 carries *Endeavour* to Los Angeles, September 21, 2012.
Source: NASA DFRC, ED12-0317-207,
<http://www.nasa.gov/centers/dryden/multimedia/imagegallery/STS-Ferry/index.html#>.



Figure 15. *Endeavour* arrives at Edwards Air Force Base, September 20, 2012.
Source: NASA DFRC, ED12-0316-05,
<http://www.nasa.gov/centers/dryden/multimedia/imagegallery/STS-Ferry/index.html#>.

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Historian: Joan Deming and Patricia Slovinac, Archaeological Consultants, Inc. (ACI), Sarasota, Florida, August 2013

Project Information: The documentation of the SCAs N905NA and N911NA was conducted in 2012 for NASA's JSC by Archaeological Consultants, Inc. (ACI), under contract to Earth Resources Technology, Inc. (ERT). It was based upon research originated in 2006 as part of a nationwide assessment of NASA's Space Shuttle Program assets, conducted by ACI. The project team consisted of architectural historian, Patricia Slovinac and project manager, Joan Deming (both with ACI). Assistance was provided by Sandra J. Tetley, JSC Historic Preservation Officer and Real Property Officer. The written narrative was prepared by Ms. Slovinac and Ms. Deming; it was edited by Ms. Tetley. The 4x5 negatives were taken by the JSC Photo Operations Group, under the direction of Maura White, JSC Photographer.

The Scope of Services for the project specifies a documentation effort following HAER Level III Standards. Information for the written narrative was primarily gathered through informal interviews with NASA and contractor personnel, research materials housed at the JSC History Office, and oral histories provided by Dr. Jennifer Ross-Nazzal, JSC Historian.