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]

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[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 the 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.