41st AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
10-13 July 2005, Tucson, Arizona

AIAA 2005-3537

Boom and Zoom: The History of the NF-104A AST

John Terry White*
Raytheon Missile Systems, Tucson, Arizona, 85734

The capstone flying curriculum experience for test pilots of the USAF Aerospace Research Pilot School in the 1960's was piloting the USAF/Lockheed NF-104A Aerospace Trainer (AST). The NF-104A was capable of zooming to altitudes in excess of 120 KFT from a ground take-off using a combination of turbojet and rocket power. A typical mission lasted less than 30 minutes with take-off and recovery taking place at Edwards Air Force Base, California. The NF-104A rocket-powered zoom mission was an intensely demanding piloting experience in that the vehicle was flown both as an aircraft and a spacecraft. This hybrid nature of the vehicle required the proficient use of aerodynamic and reaction controls in concert with trajectory energy management techniques. The pilot flew in a full pressure suit since the aircraft zoomed to altitudes well beyond the Armstrong Line. Although it did not have nearly the performance capability of the contemporaneous X-15, the NF-104A did provide many of the same spaceflight piloting experiences, albeit at much lower cost. In fact, to the 70+ men who flew a NF-104A rocket-powered zoom, the aircraft was also known as "The Poor Man's X-15".

I. Introduction

The zoom mission is one in which an aircraft trades kinetic energy for potential energy to achieve a maximum altitude far above its absolute ceiling. Military fighter pilots employ the zoom maneuver to intercept adversary aircraft at extreme altitude. The zoom flight profile also serves as a means to impart high-energy initial kinematic conditions to propulsive stages carried aloft by a zoom aircraft. Pertinent examples include the USAF F-15 ASAT Project[1] and DARPA's RASCAL Program.[2] Moreover, the USAF/North American X-15, USAF F-15 Streak Eagle, and Scaled-Composite's SpaceShipOne record-setting altitude missions used the zoom maneuver as a basis. However, history also records another significant, yet less well known aircraft that operated in the zoom flight realm. This aircraft was known as the USAF/Lockheed NF-104A Aerospace Trainer (AST) and it was the centerpiece of the flying curriculum at the Aerospace Research Pilots School (ARPS) during the 1960's. Its *raison d'etre* was to provide top ARPS students with realistic X-15-like spaceflight training at low cost. As such, the NF-104A was unofficially dubbed "The Poor Man's X-15". The aircraft (See Figure 1) was capable of attaining maximum altitudes in excess of 120,000 feet from a ground take-off using a combination of a standard J79-GE-3B turbojet and a 6000-pound-thrust LR-121-NA-1 rocket motor. The NF-104A was also configured with an X-15-type Reaction Control System (RCS) that allowed the pilot to maintain 3-axis control in near-vacuum conditions. The pilot wore an AP22S-2 full pressure suit and experienced roughly 70 seconds of zero-G flight near apogee. The view at the top of the zoom was spectacular. Here the pilot beheld a panorama that included the blue-purple-black of space above and the distinct curvature of the earth below. In the distance, the metropoli of San Francisco to the north and San Diego to the south were easily discernible. On the backside of the zoom profile, the pilot had to manage aircraft energy state to get back to Edwards and set-up for a flame out landing in the event that turbojet air-start could not be achieved. Mission elapsed time from brake release to wheels stop was approximately 30 minutes. Many of the 70+

Figure 1. NF-104A Zoom Climb

* Engineering Fellow, Aeromechanics Design Department, P. O. Box 11337/MS L5, AIAA Senior Member

pilots who flew the NF-104A rocket-powered zoom mission testify that it was the most demanding and rewarding time ever spent in the cockpit. However, with the exception of one pilot who flew the USAF/NASA X-15 and several others who went on to fly NASA's Space Shuttle Orbiter, the NF-104A would be as close as the rest would get to space. The purpose of this paper is to provide a brief overview of the previously untold story of the NF-104A; A story that is as much about the pilots and the era in which they flew as it is about the NF-104A itself.

II. Aerospace Research Pilot School

In October 1961, the United States Air Force (USAF) Experimental Flight Test Pilot School (TPS) was renamed the Aerospace Research Pilot School (ARPS).[3] This name change was reflective of the increasing role of the service relative to manned spaceflight. Recall that 1961 was the year that the Soviet Union and the United States first sent men into space. In a scant 4 months, Yuri Gagarin (USSR, 12 April), Alan B. Shepherd (USA, 05 May), Virgil I. Grissom (USA, 20 July), and Gherman Titov (USSR, 06 August) successfully flew into and returned from space. Moreover, it was in May of that year that President John F. Kennedy boldly declared that the United States should send a man to the moon and safely return him to the earth before the decade was out. Hence, the official birth of the "Space Race". Amidst these fast-paced events, the USAF perceived a significant role for the military in manned spaceflight and frankly saw itself as the lead service in that regard. It would now become a true Aerospace Force guarding a seamless earth-to-space domain. And for that to happen, it would be necessary for the air force to have its own astronauts. These astronauts would be test pilots in the truest sense of the term. Naturally, since United States Air Force test pilots were trained at the USAF Test Pilot School, air force astronauts would be trained there too. The TPS perspective was that USAF test pilots would not only be the best trained in the world, they would now be the best trained out of this world as well. However, the TPS would need a name that was more indicative of its expanded mission. The name chosen by the USAF was the Aerospace Research Pilot School.

A. ARPS Class I

The first ARPS class was known as Class I. It was comprised of five students who were also the instructors for the course! These five individuals were (in last name alphabetical order): Major Frank Borman, Major Robert S. Buchanan, Captain James A. McDivitt, Major Thomas U. McElmurry, and William G. Schweikhard (civilian).[4] To these five men fell the monumental task of synthesizing a six month course in advanced spaceflight training for the air force. This had to be done on a very spartan budget and in a period of less than six months. The ARPS curriculum consisted of various space-related academics including astronomy, trajectory analysis, orbital mechanics, rarefied gas dynamics, and meteorology. Bioastronautic training, simulator training, and flight training rounded-out the evolving curriculum. ARPS Class I started in June 1961 and graduated in December 1961. The first commandant of the ARPS was Lieutenant Colonel Robert M. Howe who served in that capacity from June of 1961until Colonel Charles E. Yeager took over as commandant in July of 1962.

B. Genesis of the NF-104A

It was recognized early in the development of the ARPS curriculum that a key element of the course involved providing test pilot students with a realistic spaceflight training experience. Using the X-15 Program as the model, this experience would include, but not be limited to, rocket-powered flight, operations at extreme altitude, the use of reaction controls, full-pressure suit flying, periods of zero-G flight, and utilization of energy management techniques. This was a tall order, not only from a technical perspective, but from a financial standpoint as well. After all, it cost the government millions of dollars per flight to launch a Mercury spacecraft or fly the X-15 where time between missions was measured in weeks or months. The ARPS needed a vehicle that provided the requisite spaceflight training virtually on demand and at much lower cost. As such, this aircraft would have to take-off and land on its own power since the use of a drop aircraft would be prohibitive both operationally and financially. Further, it would have to be a modification of an existing aircraft in order to provide a near-term capability. The ARPS staff went to work on the problem of defining, selecting, and procuring a suitable aerospace trainer. Specifically, the trio of Major Frank Borman, Major Thomas U. McElmurry, and William G. Schweikhard are credited with developing what would come to be known as the NF-104A Aerospace Trainer (AST).[5] The NF-104A was a modification of the basic Lockheed F-104A Starfighter. Under combined turbojet and rocket propulsion it was capable of zooming to altitudes in excess of 120,000 feet. While several other aircraft (e.g., a modified Convair F-102A Delta Dagger) were proposed as candidates by industry, none possessed the performance capability and operational utility of Lockheed's F-104A. Hence, a USAF contract for $5.34M was awarded in November of 1961 to the Lockheed-California Company (LCC) to modify three (3) existing F-104A aircraft for the NF-104A role.[6] Note that the "N" in the NF-104A designation stood for "non-standard".

III. The NF-104A Aerospace Trainer (AST)

The NF-104A AST external airframe configuration is illustrated in Figure 2. Numerous external and internal modifications were required to transform the F-104A into the NF-104A. Although too many to enumerate here, some of the more significant modifications are called out in Figure 3. The following sub-sections of this paper describe the major features of the NF-104A AST aircraft per the information of Reference 7 and Reference 8.

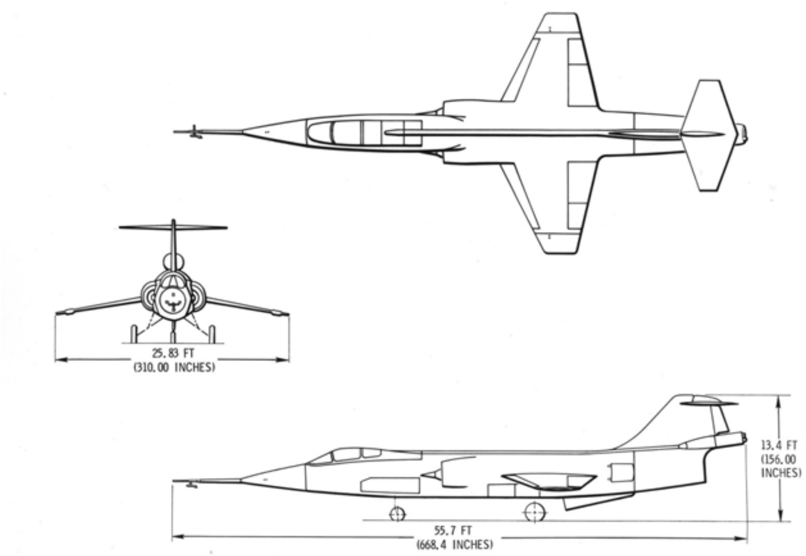

Figure 2. USAF/Lockheed NF-104A Aerospace Trainer (AST). Aircraft gross weight was approximately 22,000.

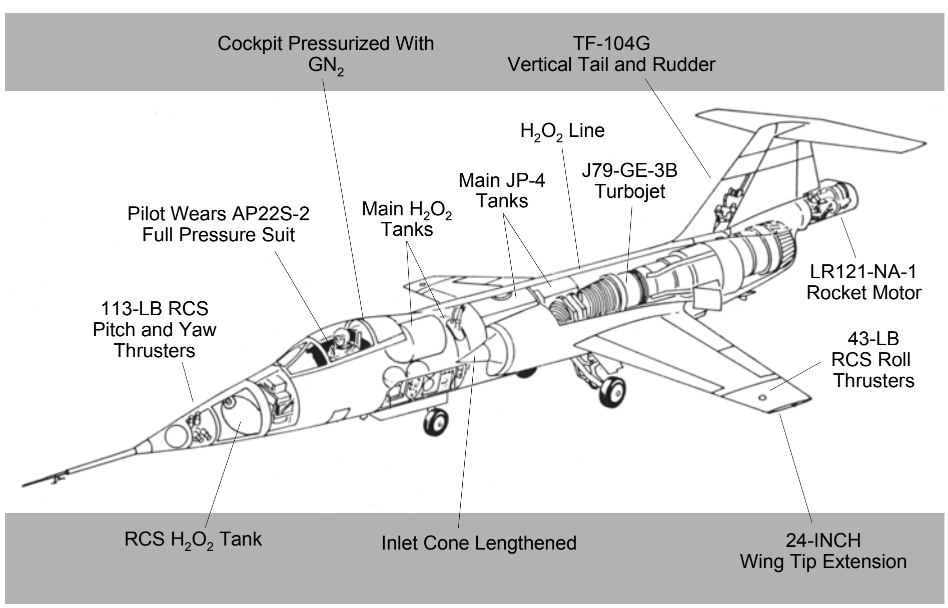

Figure 3. NF-104A Major Airframe Modifications

A. Propulsion System

The NF-104A propulsion system consisted of a General Electric J79-GE-3B turbojet engine and a Rocketdyne LR 121-NA-1 throttable rocket motor. (See Figure 4.) The turbojet and rocket motor were rated at 15,000-pounds and 6,000-pounds maximum sea level thrust, respectively. Rocket motor thrust was used (1) briefly between Mach 1.1 and 1.4 of the acceleration run-in to the zoom pull-up point and (2) during the actual zoom climb to increase the aircraft's specific energy. Both elements of the propulsion system utilized JP-4 as the fuel. Total JP-4 fuel load for a typical zoom mission was about 5000-pounds. (The rocket motor oxidizer was 90-percent pure hydrogen peroxide (H_2O_2). Roughly 2500-pounds of H_2O_2 was carried by the NF-104A which permitted a maximum rocket motor burn time on the order of 100 seconds. The rocket motor oxidizer-to-fuel ratio was on the order of 6. The tail-mounted rocket motor was intentionally canted 8.5-degrees downward with respect to the aircraft centerline so that the line of thrust went through the aircraft center-of-gravity at burnout. Doing so minimized rocket motor thrust-induced pitching moment effects as the aircraft approached the apex of the zoom trajectory.

Figure 4. NF-104A Turbojet and Rocket Motor

B. Reaction Control System

In addition to standard aerodynamic controls, the NF-104A also employed a Reaction Control System (RCS) to provide flight control at low dynamic pressure. Specifically, an X-15-type RCS was used to generate aircraft 3-axis control moments. The RCS was an acceleration command system which fired as long as the pilot depressed the firing switch for the desired thruster. Thrust was either full-on or full-off (i.e., there was no variable thrust capability). The RCS consisted of eight (8) 113-pound thrusters mounted in the nose of the aircraft and four (4) 43-pound thrusters located in the wing tips. The nose-mounted thrusters provided pitch and yaw control with two thrusters firing in each of four directions. That is, two upward firing and two downward firing thrusters provided pitch control. Likewise, two starboard-firing and two port-firing thrusters provided yaw control. Roll control was provided by the wingtip-mounted thrusters where each wingtip had a right roll and left roll-firing thruster installation. For example, right roll RCS inputs caused the upward-firing left wingtip thruster (located on the left wing lower surface) and the downward-firing right wingtip thruster (located on the right wing upper surface) to fire. Hydrogen peroxide was used as the RCS propellant. Thruster operation was based on the reaction between the hydrogen peroxide and a catalytic silver screen. The high pressure steam produced by this reaction within the combustion chamber was then expanded through the thruster nozzle to generate thrust. Manual operation of the RCS was effected via a control stick mounted on the left side of the NF-104A instrument panel. (See Figure 5 Above.) As will be discussed shortly, the RCS was also operated in an automatic mode by both the damper and kicker systems.

Figure 5. NF-104A Instrument Panel

C. Turbojet Inlet System

As mentioned previously, NF-104A airbreathing propulsion was provided by a single J79-GE-3B turbojet rated at 15,000-pounds maximum sea level thrust. Air was fed to this engine through a bifurcated duct system that routed flow processed by the starboard and port side-mounted inlets. Each inlet was configured with a conical half-spike that provided the necessary external flow compression. Since the NF-104A would be flown at a higher maximum Mach number than the stock F-104A (i.e., Mach 2.4 versus Mach 2.0), the compression spikes on the former were lengthened to provide better pressure recovery.

D. Vertical Stabilizer and Rudder

Aircraft directional stability degrades as Mach number increases supersonically. Therefore, the stock F-104A vertical tail and rudder assembly was replaced with a larger TF-104G unit to enhance the supersonic directional stability of the faster-flying NF-104A. The replacement rudder was fully-powered as opposed to the cable system employed on the standard F-104A. Although part of the new rudder was removed to accommodate the tail-mounted rocket motor installation, its net control authority was about the same as that of the original rudder since the associated planform areas were comparable.

E. Attitude and Azimuth Reference System (AARS)

A key instrument in the NF-10A cockpit was the Attitude and Azimuth Reference System (AARS) which provided inertial attitude (i.e., inertial roll, pitch and yaw angles) as well as aircraft aerodynamic attitude (i.e., angle-of-attack and angle-of-sideslip) information to the zoom pilot. Without the AARS, a maximum altitude zoom simply could not be successfully achieved. This is because the pilot had to quickly pull-up to and hold an inertial pitch angle on the order of 70-degrees in a maximum altitude zoom. Coupled with an angle-of-attack ranging from 5 to 11-degrees and a seat inclination of 14-degrees, the pilot was essentially looking straight-up inertially during the zoom climb. Further, the helmet used on the AP22S-2 pressure suit greatly restricted the pilot's peripheral vision even in the cockpit. Therefore, the NF-104A driver did not have the benefit of typical external visual cues and had to rely strictly on the AARS for attitude during the zoom climb. As a historical note, the AARS was also referred to in Lockheed technical documents as the All-Attitude Reference System.

F. AP22S-2 Full-Pressure Suit

The Armstrong Line is defined as that altitude (i.e., 63,000 feet) where space effectively begins from a human physiological standpoint. Exposure to the extremely low ambient pressures and temperatures occurring at high altitude causes ultimate and near-instantaneous death due to oxygen deprivation and boiling of body fluids. This situation is precisely the circumstance faced by astronauts flying in the vacuum of space. They must be protected from the environment and provided with proper life support systems to do so. For the NF-104A pilot, this required the use of a full-pressure suit. The then-standard USAF/David Clarke AP22S-2 full-pressure suit was used for this purpose. (See Figure 6.) Noteworthy is the fact that only the pilot's face area was supplied with pressurized oxygen while nitrogen provided pressurization below the neck. A rubber dam was fitted around the neck to separate the two gaseous environments within the suit. In addition, the NF-104A cockpit was inerted with gaseous nitrogen during that portion of the zoom mission in which the turbojet was shutdown. Gaseous nitrogen, rather than oxygen, was used for cockpit pressurization primarily as an anti-fire measure. This meant that the pilot could not open his face plate during the inerting period without risking an unconsciousness from which he would not awaken.

Figure 6. NF-104A Pilot Major Warren J. Kerzon

IV. The NF-104A Zoom Flight Mission

The NF-104A AST rocket-powered zoom mission was a fast-paced and demanding piloting experience. The flight plan had to be committed to memory and precise flight path control was required to extract maximum performance from the aircraft. The NF-104A was flown both as an airplane with aerodynamic controls and as a spacecraft with reaction controls. Pilot attention had to continually be focused on keeping aircraft inertial attitude, energy state, aerodynamic attitude, and turbojet exhaust gas temperature (EGT) within prescribed limits. Failure to do so always decreased performance and could (and did on one occasion) cause loss of aircraft. All NF-104A rocket-powered zoom missions were flown from and recovered to Edwards Air Force Base (EAFB), California.

(The exception here being the contractor Category I test flights which originated from nearby Air Force Plant 42 in Palmdale, California.) The zoom missions were flown in the supersonic corridor region of the expansive EAFB reservation. Prior to 1964, the acceleration run-in to the zoom pull-up point was flown west to east starting at a location over the Pacific Ocean. From 1964 on, the acceleration run-in was flown east to west starting at a point near the California-Arizona border.

To begin a zoom climb mission, the NF-104A performed a full-afterburner take-off with nose wheel rotation and main gear lift-off occurring at 185 KIAS (Knots Indicated Air Speed) and 210 KIAS, respectively. During the climbout, the aircraft was allowed to accelerate to 400 KIAS at which point the throttle was retarded to military power. Acceleration continued at this throttle setting to 450 KIAS. The aircraft continued to climb at this airspeed until reaching 0.86 IMN (Indicated Mach Number). This Mach number was then held for the remainder of the climb to 35,000 feet pressure altitude. The NF-104A subsequently cruised to the turn-around point located roughly 100 NM from Edwards. The aircraft then executed a 180-degree turn to align itself along the inbound zoom heading. The zoom acceleration run-in began at 0.9 IMN and 35,000 feet pressure altitude as the throttle was advanced to full afterburner. Rocket power was briefly used between 1.1 and 1.4 IMN to allow the aircraft to more quickly transit the transonic drag rise region. From 1.4 IMN to about 1.8 IMN, the aircraft accelerated under full-afterburner turbojet power only. Beyond this point and preparatory to arriving at the pull-up Mach number, rocket power was again used to augment turbojet thrust until hydrogen peroxide depletion occurred near the zoom apex. The zoom climb was initiated with a 3.5G pull-up when the NF-104A arrived at 2.2 IMN. (See Figure 7.) Note that these are flight manual nominals. In fact, pull-up normal acceleration and Mach number on maximum performance zooms were as high as 4G's and 2.4 IMN, respectively. The pull-up was continued until the target inertial pitch angle was intercepted. On maximum performance zooms, this angle was as typically 70-degrees. As the pilot attempted to hold the NF-104A at this target pitch angle, the angle-of-attack naturally increased as the aircraft ascended. That is, the decreasing dynamic pressure associated with altitude gain and decreasing velocity (See Figure 8) required increased angle-of-attack to generate the lift required to hold the target inertial pitch angle. The aircraft angle-of-attack was allowed to increase until a maximum allowable value (11 to 15-degrees) was intercepted. This limitation on angle-of-attack was in deference to aircraft control considerations. The primary concern being possible departure from controlled flight due to exceedance of the NF-104A pitch-up angle-of-attack (14 to 19-degrees). In addition to closely monitoring aircraft inertial pitch angle and angle-of-attack, the NF-104A pilot had to monitor the rise in exhaust gas temperature (EGT) to avoid damaging the J-79 turbojet. The EGT rise is a natural consequence of the decreased density that attends altitude increase. As the aircraft passed through 63,000 feet, the throttle was brought out of afterburner to military power. Subsequently, the throttle was moved to the OFF detent as the aircraft flew through 80,000 feet. Engine rotor speed at shutdown was on the order of 7400 RPM and would continually decay until air-start occurred on the descending leg of the zoom trajectory. Turbojet air-start was usually attempted beginning at 70,000 feet by which point the rotor speed had decayed to roughly 60 percent of the shutdown value. J-79 air-start was almost always successful during NF-104A zooms with few recorded instances of an NF-104A being forced to

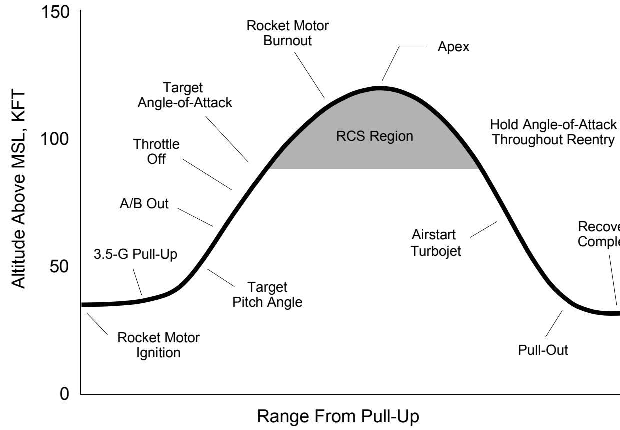

Figure 7. Key Zoom Climb Events

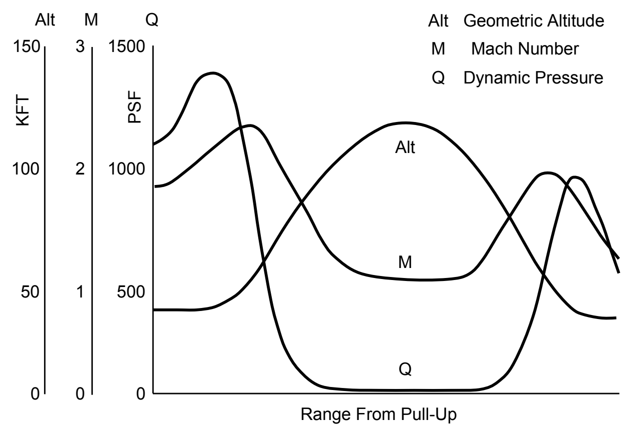

Figure 8. Zoom Flight Parameter Variations

land dead-stick. One of the great benefits of recovering the aircraft back at Edwards was the availability of Rogers Dry Lake for just such situations.

Reaction controls were required to augment the aerodynamic controls as the NF-104A ascended past 90,000 feet. This was due to the rapidly decreasing dynamic pressure as the aircraft approached the zoom apex. Flight control at the zoom apex was provided entirely by the RCS. Minimum dynamic pressures as low as 2 PSF were encountered on several zooms above 118,000 feet. The bulk of the 3-axis control task was handled via pilot manual inputs. However, RCS dampers were also used to provide automatic control of airframe random disturbances. Note that the pilot's manual inputs always overrode the damper system. It was critical that the aircraft angle-of-attack be controlled over the top and kept below the pitch-up value in anticipation of reentry. Failure to do so could lead to a situation where the RCS pitch control authority was not sufficient to overcome the large and unstable aerodynamic pitching moment generated during the early stages of reentry. The magnitude of this unstable aerodynamic pitching moment becomes large due to the combination of (1) high angle-of-attack and (2) rapidly increasing dynamic pressure. Even though elevator pitch control effectiveness is also increasing as the dynamic pressure increases, the elevator does not have sufficient control authority to prevent control departure. The result is that the aircraft goes through a series of post-stall gyrations and eventually ends up in a spin. This spin may be either steep or flat in nature. If it is the latter, there is no aerodynamic means (with the exception of anti-spin or drag chute deployment) with which to regain control of the aircraft. The pilot then has no other recourse but to eject. This situation did in fact occur on the afternoon of 10 December 1963 when NF-104A S/N 56-0762 crashed to destruction following a zoom to 101,600 feet. The pilot on that particular flight was Colonel Charles E. Yeager who was serving as the ARPS Commandant. Yeager ejected from the aircraft roughly 5000 feet above ground level following a vain attempt to recover from a flat spin. Although badly burned during the bailout and parachute deployment process, he parachuted to safety and was quite fortunate to have survived the experience.

Returning now to a description of a typical zoom mission, a successful zoom apex traversal and reentry was flown by maintaining a constant angle-of-attack (5 to 11 degrees) through pull-out. Prior to turbojet air-start, between altitudes of 90,000 and 75,000 feet of the reentry, the NF-104A typically experienced lateral-directional oscillations due to alternating spillage of flow from the side-mounted inlet ducts. Airframe buffet then occurred around 75,000 feet. The first attempt to air-start the J-79 turbojet would then take place as the aircraft passed through about 70,000 feet. Completion of the reentry and pull-out would vary between 55,000 and 40,000 feet. The Mach number at this point would be on the order of 2.0. Given that the air-start was successful, landing and rollout took place on the main runway at Edwards. The infrequently-experienced flame-out landings usually took place on Rogers Dry Lake. Regardless of the turbojet operational status on the return to Edwards, the entire NF-104A zoom flight mission from brake release to wheels stop took place in about 30 minutes or less.

V. Zoom Flight Peculiarities

The NF-104A zoom mission was unique in that the vehicle had to be flown both as an aircraft and as a spacecraft. As such, the pilot had to be equally adept with the use of aerodynamic and reaction controls. Precise flight path and vehicular control techniques were required for the mission to be safely conducted and for maximum zoom performance to be achieved. In short, the pilot had to (1) have an intimate knowledge of the ever-changing flight mechanics of the zoom flight environment and (2) apply that knowledge in spite of its sometimes anti-intuitive nature. The following discussion highlights some of the more significant aspects of the zoom experience per Reference 9 and Reference 10.

A. Zoom Flight Modes

The zoom trajectory exhibits two characteristic regions or modes of flight. (See Figure 9.) For this discussion, they will be referred to as the (1) aero-effective mode (AEM) and the (2) quasi-ballistic mode (QBM). The former is characterized by high dynamic pressure since the vehicle velocity is highest here and the altitude is relatively low. Hence, aircraft angle-of-attack will provide lift sufficient to generate the normal acceleration required to turn the flight path upward. It is here that the target inertial pitch angle is

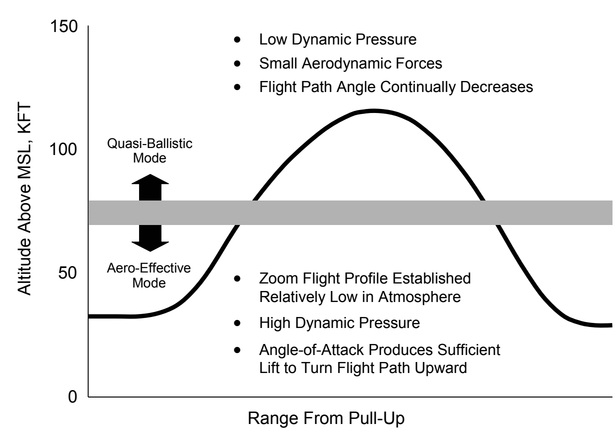

Figure 9. Zoom Flight Modes

achieved and the ultimate character of the zoom profile is established. That is, the altitude ultimately realized on a given zoom mission is largely determined early in the zoom. And the pilot's ability to quickly attain and hold the target inertial pitch angle are key factors in this regard. As the aircraft ascends and slows, the dynamic pressure rapidly falls and it becomes increasingly difficult to generate lift sufficient to hold the target inertial pitch angle and to generate normal acceleration within the previously-cited angle-of-attack constraints. As the maximum normal acceleration falls below 1G, the flight path angle (i.e., the difference between the inertial pitch angle and the angle-of-attack) begins a continual decrease. This point occurred around 75,000 feet (± 5000 feet) for the NF-104A and it marked the beginning of quasi-ballistic flight. This flight mode is characterized by very low dynamic pressures wherein aerodynamic lift and drag forces are correspondingly small. These small magnitude aerodynamic forces do not significantly affect the shape of the flight path. This condition is essentially the classic case of projectile motion in a vacuum. Hence, in the quasi-ballistic mode, aircraft angle-of-attack results only in a change of the inertial pitch angle, not the flight path angle.

B. Zoom Apex Flight Control

NF-104A zoom pilots observed that the aircraft angle-of-attack (α) naturally tended to increase in the vicinity of the zoom apex. Figure 10 identifies the principal factors that affect the aircraft angle-of-attack rate. The first term on the right-hand side of the equation reflects the natural tendency of the aircraft angle-of-attack rate (and hence angle-of-attack) to build-up. It is governed by the inertial velocity (V), pitch angle (θ), and roll angle (ϕ). For wings level flight (i.e., inertial roll is zero), the largest angle-of-attack rate occurs near the apex of the trajectory where velocity is a minimum and the inertial pitch angle is small. The effect of the third term is to either amplify or diminish the angle-of-attack rate depending upon the signs of aircraft roll rate and angle-of-sideslip. In any event, its contribution was typically very small since roll rate and angle-of-sideslip were small. The fourth term affected the angle-of-attack rate in a minor way since dynamic pressure was quite low at the top of the zoom. Finally, the second term of the subject equation shows that pilot control of the NF-104A pitch rate was required to counter the natural tendency of the zoom trajectory angle-of-attack to build-up. Specifically, a nose-down RCS input (i.e., negative pitch rate) was the instrumentality through which the angle-of-attack rate was controlled.

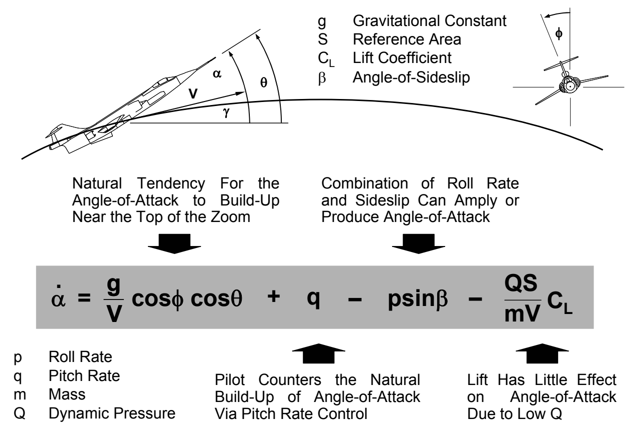

Figure 10. Factors Affecting Angle-of-Attack Rate

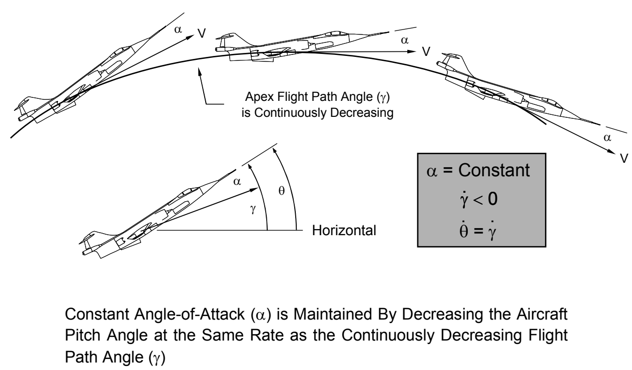

Figure 11. Maintaining Constant Angle-of-Attack

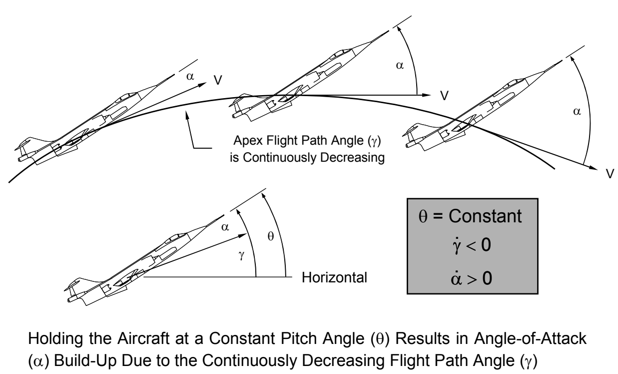

Figure 12. Maintaining Inertial Pitch Angle

Further discussion is warranted regarding the interplay amongst the inertial pitch angle, angle-of-attack, and flight path angle (γ). We first note that the flight path angle is continually decreasing in the vicinity of the zoom apex with values being positive before the apex, zero at the apex, and negative beyond the apex. Since the NF-104A is in quasi-ballistic mode (QBM) at this point, the pilot has no control of the flight path. That opportunity took place earlier in the zoom while the aircraft was still operating in the aero-effective mode (AEM). Hence, the flight path that the aircraft is now traversing is the product of how it was flown in the lower atmosphere. However, the pilot can and must control the aircraft inertial pitch attitude and angle-of-attack. This is effected using the RCS pitch thrusters for wings level flight. Figure 11 shows that angle-of-attack is held constant by reducing the inertial pitch angle at the same rate as the flight path angle decreases. Figure 12 underscores the fact that merely holding the inertial pitch angle constant results in angle-of-attack build-up due to the continuously decreasing flight path angle.

C. Engine Gyroscopic Effects

The rotational momentum produced by the rotating machinery within the J-79 turbojet made the engine act like a gyroscope. That is, it would couple motion in pitch with that in yaw or vice-versa. Figure 13 illustrates this phenomenon for pitch rate effects. Here, engine rotation couples nose-down pitch rate into a nose-left yawing moment while a nose-up pitch rate results in a nose-right yawing moment. Figure 14 illustrates the gyroscopic effects due to yaw rate. Specifically, engine rotation couples nose-right yaw rate into a nose-down pitching moment while a nose-left yaw rate results in a nose-up pitching moment. These gyroscopic coupling effects are at play any time the engine has rotational momentum and the aircraft rotational rate vector is non-zero. However, the extent to which they influence aircraft dynamic motion depends on the relative magnitude of the 3-axis aerodynamic moments. Large aerodynamic moments tend to mask the influence of engine gyroscopic effects due to the typically small magnitude of the latter. This is the case for flight in the aero-effective region of the zoom where the dynamic pressure is high. However, the disparity between the engine-induced gyroscopic and aerodynamic moments decreases rapidly as the aircraft ascends and the dynamic pressure correspondingly falls-off. At the top of the zoom, where dynamic pressure can be as low as 2 PSF, the engine gyroscopic effects were quite noticeable to the NF-104A pilot and factored into his efforts to control aircraft attitude. As illustrated

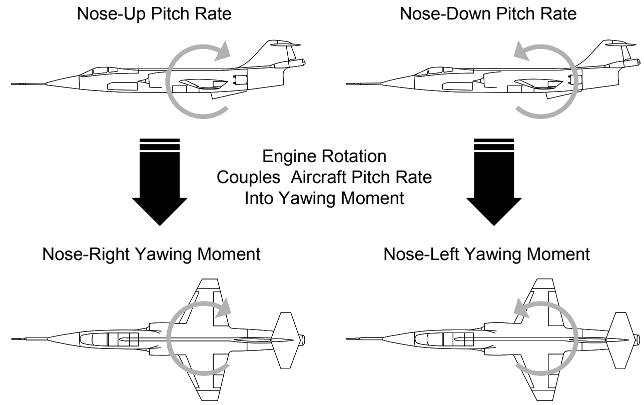

Figure 13. Turbojet Gyroscopic Pitch-Yaw Coupling

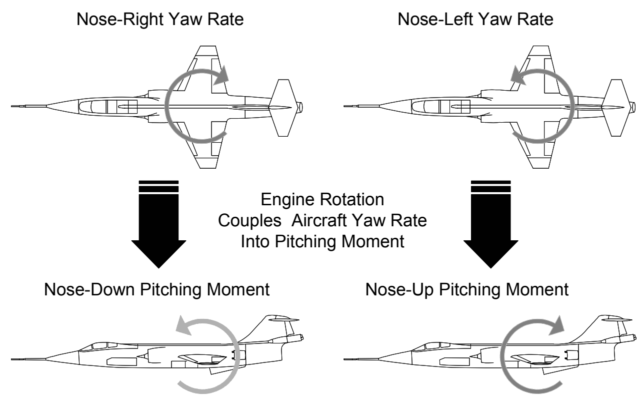

Figure 14. Turbojet Gyroscopic Yaw-Pitch Coupling

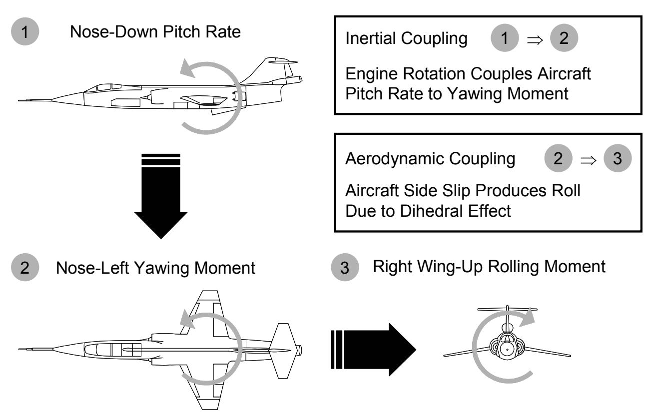

Figure 15. Aerodynamic-Inertial Coupling

in Figure 15, the inertial coupling produced by the engine gyroscopics could also lead to aerodynamic coupling via the aircraft dihedral effect. That is, the generation of yaw due to engine gyroscopics would cause the aircraft to roll due to sideslip. However, this aerodynamic coupling effect was typically small since (1) the dynamic pressure level was low and (2) the pilot usually kept aircraft rates at low levels.

D. Pitch-Up

Pitch-up is a phenomenon wherein an aircraft flying near the stall angle-of-attack experiences a sudden reversal in pitching moment slope. There is a resulting rapid build-up in angle-of-attack which can lead to uncontrolled flight in the event that the elevator pitch control authority is exceeded. In this circumstance, the aircraft can see angle-of-attack excursions as large as 50 to 70 degrees. The danger here is that the aircraft may trim out at a very high angle-of-attack. This is a deep stall condition from which recovery is not likely. An aircraft configured with a T-tail (like the NF-104A) is particularly prone to pitch-up. This is due to a marked decrease in pitch control effectiveness caused by the tail being immersed in the wing wake flow region. The NF-104A inherited this interesting characteristic from its F-104A forebear. Figure 16 shows that, depending on elevator deflection, the pitch-up angle-of-attack at a Mach number of 0.9 varies from approximately 14 to 19 degrees.

In the vicinity of the zoom apex, the RCS has sufficient control authority to overcome the aerodynamic moment, even at large angles-of-attack, as long as the dynamic pressure is below a critical threshold (See Figure 17). Thus, for the same reasons that it provides no influence in shaping the zoom apex flight path, flying at angles-of-attack beyond pitch-up will not translate to a loss of control if the dynamic pressure is very low. The real issue for the NF-104A pilot was maintaining the angle-of-attack well below the pitch-up value as the reentry was initiated. Here, the precipitous rise in dynamic pressure would generate aerodynamic pitching moments greatly in excess of what the RCS could handle if the angle-of-attack was beyond that for pitch-up. This would result in the pilot having no pitch control authority either aerodynamically or propulsively. The zoom aircraft would then go through a series of post-stall gyrations followed by entrance into some type of spin.

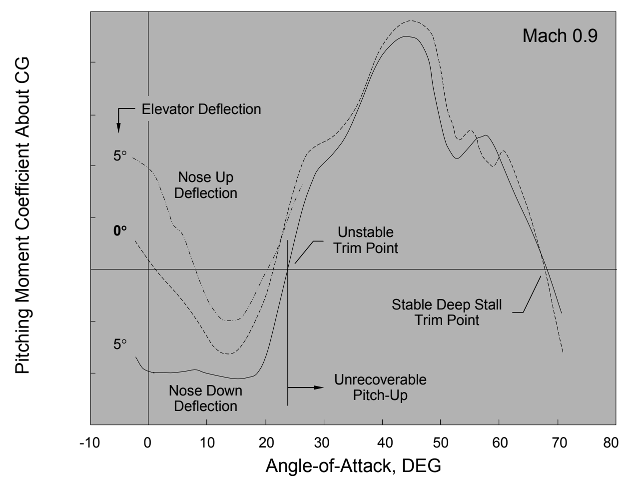

Figure 16. NF-104A Pitching Moment Characteristics

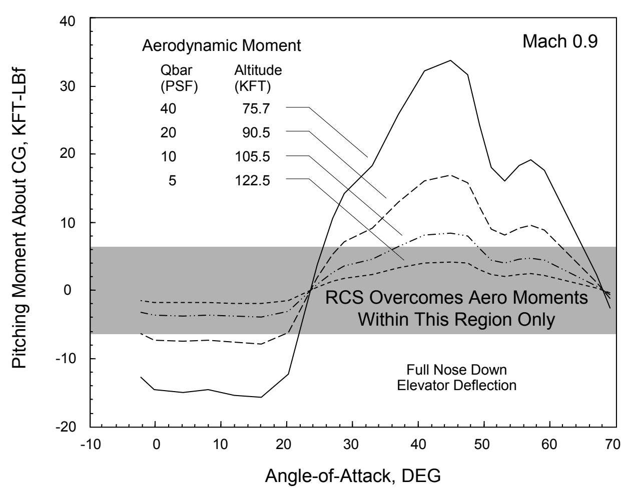

Figure 17. High Altitude RCS Pitch Control

E. High Altitude Spins

A spin is a form of uncontrolled flight in which the aircraft is essentially falling vertically and rotating about an axis offset from the aircraft center-of-gravity. Figure 18 diagrams the situation for a steady-state spin (with wings level) in which the aircraft spin rate and inertial velocity are constant. Hence, the forces perpendicular and parallel to the spin axis are in equilibrium. That is, aircraft lift opposes the centrifugal force of the spin and aircraft drag is equal and opposite to aircraft weight. The spin radius is defined as the distance between the spin axis and the aircraft center-of-gravity. Note that the spin rate is a combined body axis roll and yaw motion. A spin is characterized as being either steep or flat is nature (See Figure 19). The angle-of-attack is on the order of 30 degrees for the former and greater than 60 degrees for the latter. A steep spin has an oscillatory nature in which the aircraft nose alternately rises above and falls below the horizon. Standard spin recovery techniques take advantage of this oscillatory nose bobbing motion to aid in returning the aircraft to controlled flight. A flat spin has a higher spin rate and both a lower spin radius and inertial velocity than a steep spin. The flat spin is really a deep stall condition with the aircraft spinning in a steady, non-oscillatory manner while it falls near-vertically. It is insidious in that recovery therefrom is exceedingly difficult. An anti-spin chute is required and there must be sufficient altitude in which to (1) stop the spin, (2) enter a dive to pick-up airspeed, (3) jettison the chute, (4) pull out of the dive, and (5) return to level flight. Further, at spin chute jettison, the pilot must anti-intuitively push the control stick *forward* to avoid an immediate pitch-up back into a flat spin. Note that pitch-up is not the only path to spin entrance. Mechanisms such as (1) aerodynamic-inertial coupling associated with engine gyroscopics and (2) aerodynamic coupling due to very high roll rates can also result in departure from controlled flight leading to spin entrance.

F. Damper and Kicker Systems

The NF-104A was configured with both aerodynamic and RCS damper and kicker systems that assisted the pilot in maintaining control of the aircraft throughout the various phases of the zoom mission. A brief description of these systems now follows:

1. Damper Systems

NF-104A aerodynamic stability augmentation was provided in roll, pitch, and yaw via automatic control of the ailerons, horizontal tail, and rudder, respectively. Rate gyros sensed 3-axis flight perturbations and the damper system provided excitation of the appropriate control surfaces to damp out undesirable oscillations. Note that pilot inputs overrode the damper system during active maneuvering of the aircraft.

The NF-104A also incorporated a RCS damper system to augment aircraft stability in the vicinity of the zoom apex. Like its aerodynamic counterpart, the RCS damper system provided automatic damping in all 3-axes with pilot inputs overriding the automatic system. The RCS dampers only fired one thruster in the requested channel when activated so that manual operation (which fired two thrusters) could handle a system hardover condition.

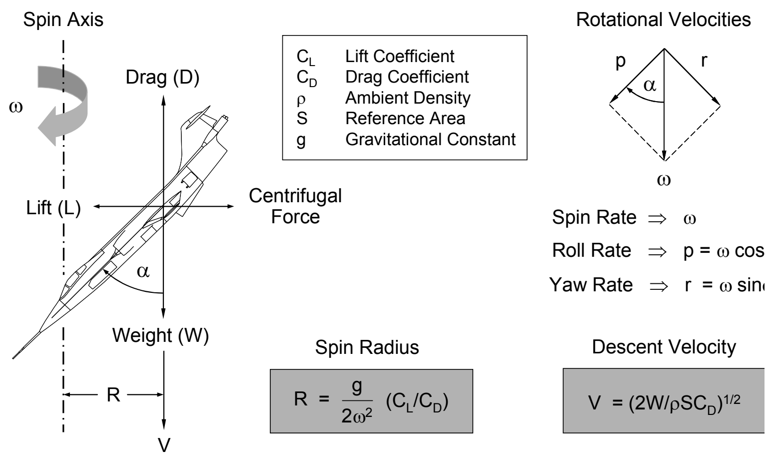

Figure 18. The Steady-State Spin

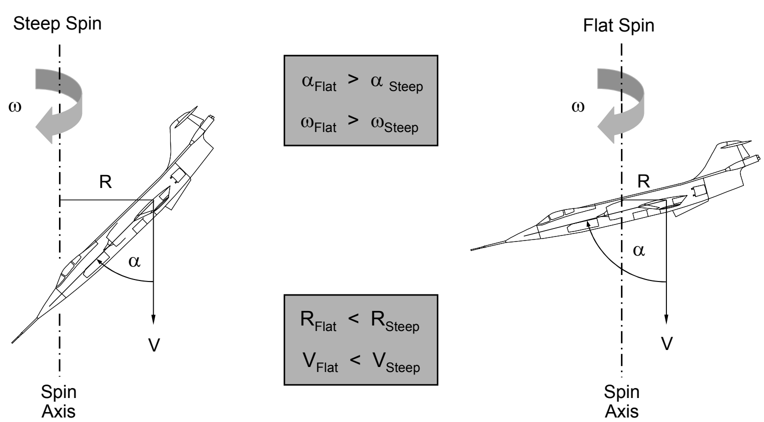

Figure 19. Distinction Between Steep and Flat Spin Modes

2. Kicker Systems

The Automatic Pitch Control (APC) system of the stock F-104A was retained in the NF-104A AST. The APC was used to counter an incipient stall condition by automatically shoving the control stick forward to reduce the angle-of-attack of the aircraft. Activation of the APC was based on experimentally-derived criteria involving a combination of aircraft angle-of-attack and pitch rate. The pilot could not override this system.

After the loss of A/C 56-0762, RCS kickers were installed on the two remaining NF-104A aircraft to help prevent angle-of-attack build-up in the vicinity of the zoom apex. The RCS kicker system automatically fired the pair of nose-down thrusters whenever the aircraft angle-of-attack exceeded 15-degrees. Firing of these thrusters continued until the aircraft angle-of-attack was driven down to 13-degrees.

VI. NF-104A Flight History

The NF-104A AST flew from 09 July 1963 through 20 December 1971. As shown in the chronology of Figure 20, the life of the program consisted of five (5) separate phases. As will shortly be described, there were two (2) distinct eras in which the NF-104A operated. In Era 1, the NF-104A was flown at its maximum zoom capability. In Era 2, the aircraft was restricted in its performance. The defining event that distinguishes Era 1 from Era 2 is the flight mishap involving USAF aircraft 56-0762 that occurred on the afternoon of Tuesday, 10 December 1963. More will be said later on this topic. Suffice it to say for now that the post-mishap restriction placed on NF-104A zoom performance deprived the vast majority of those who flew the aircraft of fully reaping the benefits intended by its ARPS and LCC creators.

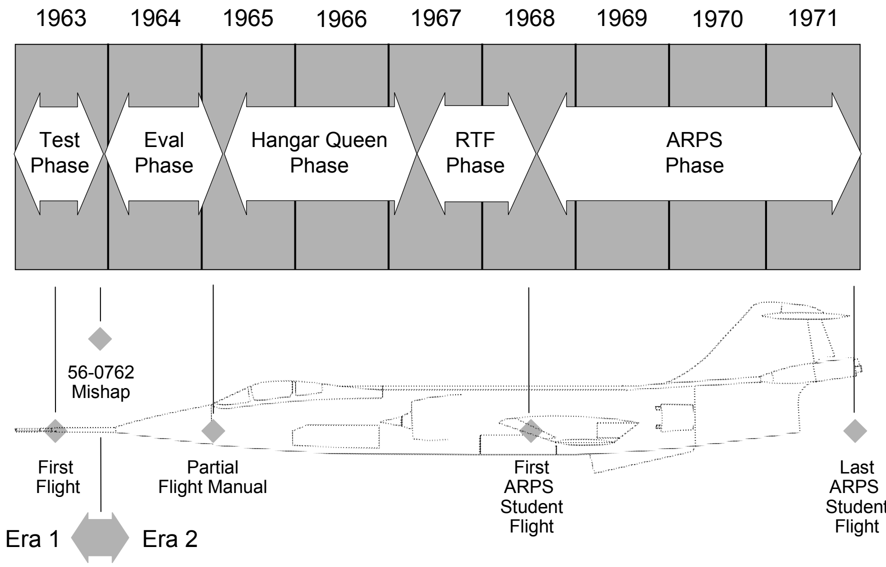

Figure 20. NF-104A Program Chronology

A. Test/Record Attempt Phase

Three (3) USAF F-104A airframes were converted to the NF-104A Aerospace Trainer (AST) configuration by the Lockheed-California Company (LCC); USAF S/N 56-0756, S/N 56-0760, and S/N 56-0762. Table 1 identifies the LCC Ship Numbers associated with each of these aircraft and provides a summary of key events in the conversion process. Contractor testing of the NF-104A began on 09 July 1963 using aircraft 56-0762. This testing consisted of a limited 42-flight Category I test program flown out of Palmdale, California (USAF Plant 42). This testing involved functional checkout flights, stability and control evaluation, rocket motor performance, RCS evaluation, and rocket-powered zooms. The contractor test pilot for the NF-104A was Jack F. Woodman (See Figure 21), a former Canadian Air Force pilot. Woodman flew the majority of the Category I test flights. The exceptions were 3 flights flown by another Lockheed test pilot (Eddie W. Brown) and 4 flights by USAF Major Robert W. Smith, NF-104A Project Pilot (See Figure 22). Although Woodman flew the first NF-104A rocket-powered zoom, it was Smith who flew the highest Category I zoom (118,860 feet on 22 October 1963 in A/C 56-0756).[11] Woodman followed a day later with a zoom to 118,400 feet in A/C 56-0760. On that particular flight, Woodman lost control of the aircraft as he approached the zoom apex. The aircraft ultimately entered a steep spin from which recovery took place at 35,000 feet. Post-flight inspection of the aircraft revealed that this event was not

Event	S/N 56-0756	S/N 56-0760	S/N 56-0762
USAF Aircraft Delivered to LCC	17 Sep 1962 (Ship 1044)	06 Sep 1962 (Ship 1048)	20 Aug 1962 (Ship 1050)
Aircraft Enter LCC Flight Test	24 May 1963	14 Jun 1963	22 Apr 1963
First Flight	10 Aug 1963	13 Sep 1963	09 Jul 1963
Aircraft Returned To USAF	29 Oct 1963	30 Sep 1963	25 Oct 1963

Table 1. Key Dates in Early Development of the NF-104A

due to pilot error. In point of fact, the RCS had not been serviced properly on the ground prior to the flight! As an aside, Brown made a single zoom attempt in A/C 56-0756 on 24 October 1963, but had to abort due to a problem with (what else?) the RCS.

The air force took receipt of all three (3) NF-104A by 29 October 1963 and continued flight testing with Major Smith as the project pilot. All flights would now originate from and recover to Edwards Air Force Base (EAFB), California (about 30 miles from Palmdale). Smith continued to fly zoom missions recording altitudes of 114,400 feet and 115,750 feet in A/C 56-0760 on 14 November 1963 and 19 November 1963, respectively. He also joined Jack Woodman in having the experience of recovering the NF-104A from zoom-induced departed flight. Specifically, Smith zoomed A/C 56-0760 on 05 December 1963 to an altitude of 112,300 feet. On this flight, Smith made the pull-up at a target inertial pitch angle of about 85 degrees in an ill-advised attempt to find the aircraft's true maximum altitude. The idea was to delay the push-over to 100,000 feet and then push-over using combined aerodynamic and RCS control inputs. Not good. The aircraft ran out of energy before the push-over could be completed and simply tail-slid out of control. Smith described the ensuing tumbling motion as a "whifferdill" in which he occasionally would pick-up sight of the ground. However, for the most part he spent his time trying to make sense of the roll, pitch, and yaw indications available from the AARS. Incredibly, Smith recovered *inverted* while going over the top. This was followed by another brief loss of control during the early part of reentry from which recovery was also successfully executed. Smith recovered from this second battle with uncontrolled flight at 35,000 feet in a direction that was 110 degrees from the original zoom heading. Note that Smith categorized neither of these departed flight episodes as spins.

Having taken notice of the unique performance capabilities of the NF-104A, ARPS Commandant Colonel Charles E. Yeager suggested that the aircraft be used to reclaim the world absolute altitude record from the USSR.[12] The existing record was 113,892 feet established on 28 April 1961 in a E-66A (a modified MiG 21) with Georgi Mossolov at the controls.[13] (Note that the record in question was with respect to a ground take-off aircraft. This excluded aircraft such as the X-15 which was air-launched from a mothership.) Yeager further suggested that the record be broken on or before the 60th anniversary of powered flight (i.e., 17 December 1963). USAF command accepted this suggestion and appointed Yeager to be the record attempt project pilot. However, up to this point, Yeager had never even flown the NF-104A. Ironically, the man tasked with helping Yeager learn to proficiently fly an NF-104A rocket-powered zoom to record altitude was Major Smith; the man who this author refers to as "Mr. NF-104A".

Although a lesser individual may have done otherwise, Major Smith became the consummate team player and prepared Colonel Yeager for the impending record attempt. Historical records[14] indicate that Yeager flew his first rocket-powered zoom in A/C 56-0760 on 04 December 1963. The maximum altitude achieved was 94,500 feet. The highest altitude that Yeager would ever zoom the NF-104A was 110,500 feet. This took place on 06 December 1963 in A/C 56-0760. Smith zoomed the same aircraft on the same day to an altitude of 120,800 feet. This mark stands as the highest NF-104A zoom. It surpassed the Soviet record by 6%, which was double the required minimum. However, Smith's record was then and remains to this day

Figure 21. Jack F. Woodman

Figure 22. Major Robert W. Smith

Figure 23. Colonel Charles E. Yeager

an unofficial mark for a United States aircraft. The reason it was not official was because neither the FAI record-verifying process or equipment were in place for this flight. The Soviets extended the official record to 123,524 feet on 31 August 1977 using a Ye-266M (a modified Mig-25) piloted by Alexander Fedotov.[15] Interestingly, had Smith's altitude mark been official, the Soviets attempt would not have been enough to qualify as a record since it did not exceed Smith's altitude by the minimum 3%.

Colonel Yeager flew the NF-104A to 110,000 feet on 09 December 1963 in A/C 56-0760. On the morning of Tuesday, 10 December 1963, Yeager zoomed the same aircraft; this time to 108,700 feet. Around 1400 hours of the same day, Yeager took-off from EAFB in A/C 56-0762. The zoom apex altitude on this flight was only 101,600 feet (See Figure 24) with the rocket motor burning-out about 5 seconds post-apogee. That is, the aircraft was already on the descending leg of the zoom trajectory and in the early stages of reentry. Yeager reports that the aircraft angle-of-attack at that point was about 50 degrees;[16] a figure that is well past the NF-104A pitch-up angle-of-attack. He had flown the aircraft this way on previous flights and had always been able to lower the nose via RCS inputs.

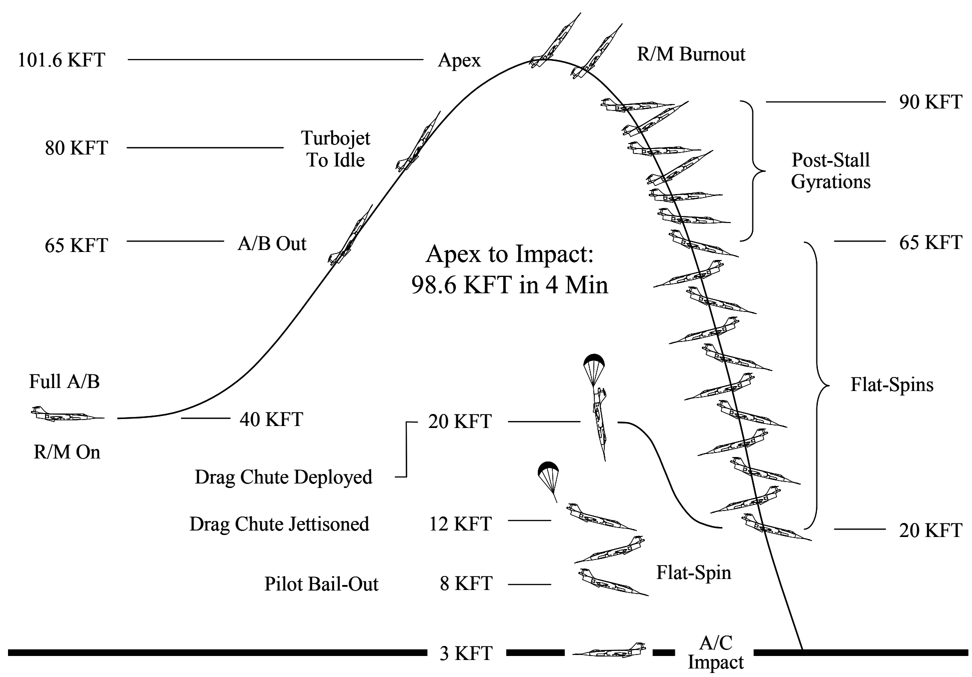

Figure 24. Loss of NF-104A S/N 56-0762 on 10 December 1963

However, on this day the RCS did not have sufficient control authority to bring the nose down and the aircraft began the reentry in a very nose-high attitude. As the dynamic pressure rapidly built-up, the aircraft departed control flight and went through a series of post-stall gyrations between 90,000 and 65,000 feet. These gyrations ultimately led to a series of flat spins (with a period of 6 seconds per cycle) occurring between 65,000 and 20,000 feet. Major Smith was monitoring the flight at the base and urged Yeager to deploy the drag chute to act as an anti-spin device. This Yeager did do and in fact the flat spin was arrested. Airspeed picked-up to 180 KIAS with the aircraft hanging in the chute, but Yeager was unable to get an air-start on the J-79 which had spooled down to 6% of maximum RPM. At 12,000 feet, Yeager jettisoned the drag chute and the aircraft immediately pitched-up into a flat spin. About 3/4 of the way through the spin cycle, Yeager ejected around 8,000 feet (with ground level being 3,000 feet). The aircraft hit the ground first and in a very flat attitude. Yeager landed close to the airplane and was in a great deal of pain due to burns he received during the bailout process. Total time from zoom apex to pilot touchdown was on the order of 4 minutes. Shortly after Yeager landed, a H-21 "Flying Banana" helicopter arrived in the impact area (See Figure 25) which was located about 15 NM northwest of the base. The pilot was Captain Phil Neale and his observer was none other than Major Robert W. Smith. Neale and Smith transported Yeager back to the base hospital for emergency treatment of his disturbingly visible and painful facial and hand burns.

A Mishap Investigation Board (MIB) was convened immediately following the loss of A/C 56-0762 with USAF Colonel Guy M. Townsend as board president. The story of this MIB[17], its workings, and its determinations is one that is too involved and intrigue-laden to recount here. However, based on extensive review and analysis of information available at the Air Force Flight Test Center History Office[18] as well as interviews conducted with individuals quite familiar with this aspect of the NF-104A story, it is evident that pilot error played a major role in the loss of A/C 56-0762. The aircraft simply was not flown in a manner commensurate with the physics of the zoom environment. Indeed, Jack F. Woodman and USAF Major Robert W. Smith had zoomed the NF-104A significantly higher and very near the theoretical maximum. The critical importance of quickly intercepting and maintaining target inertial pitch angle during pull-up had been repeatedly demonstrated as had correct control of angle-of-attack during reentry. Yeager did not achieve similar altitude performance on any of his zooms because he did not intercept and maintain the required pitch angle during aero-effective flight. Further, he consistently flew the NF-104A over the top at angles-of-attack well beyond the pitch-up value. RCS control authority was sufficient to lower the nose to sub-pitch-up angles-of-attack just prior to reentry on all but the mishap flight. Unfortunately, the low apex altitude of that zoom resulted in a higher dynamic pressure that, in conjunction with very high angles-of-attack, produced an aerodynamic pitching moment that the RCS could not overcome.

Figure 25. NF-104A S/N 56-0762 Crash Site

B. Evaluation Phase

Following the A/C 56-0762 mishap and the subsequent investigation in late 1963, an extensive flight evaluation of the NF-104A was conducted by the air force. The goal of the study was to establish a rigorous set of zoom mission operational flight rules that would minimize risk for ARPS student pilots while still providing a meaningful training experience. Major Robert W. Smith was retained as NF-104A Project Pilot and Clendon L. Hendrickson was named as the Project Engineer. The study period lasted from January 1964 to March 1965. By study's end, Major Smith had accumulated 126 flights in an NF-104A cockpit which made him far and away the most experienced and accomplished of those who would ever fly the aircraft in a rocket-powered zoom. The primary products from this test work were the NF-104A Partial Flight Manual that Smith authored as well as FTC-TR-65-37 which was authored by Clendon L. Hendrickson. (While his name also appears on the report, Smith privately claims no part in the writing thereof!) The latter report obligingly confirmed the study's premise that the zoom mission as originally conceived was too demanding for an ARPS student pilot. As a result, a number of restrictions were placed on NF-104A zoom flight performance. The most significant restrictions were: (1) a 50-degree maximum inertial pitch angle, (2) a maximum pull-up Mach number of 2.15, (3) a maximum angle-of-attack of 8 degrees, and (4) a minimum dynamic pressure at the zoom apex of 20 PSF. The net effect of these restrictions would be to limit the NF-104A maximum attainable altitude to about 108,000 feet. Thus, with only a very few exceptions, the NF-104A would never again zoom beyond 110,000 feet. Table 2 summarizes the 12 highest NF-104A rocket-powered zooms.

Altitude AMSL	Aircraft	Date	Pilot
120,800 FT	56-0760	06 Dec 1963	Maj R. W. Smith, USAF
118,860 FT	56-0756	22 Oct 1963	Maj R. W. Smith, USAF
118,400 FT	56-0756	23 Oct 1963	J. F. Woodman, LCC
118,300 FT	56-0760	05 Dec 1963	Maj R. W. Smith, USAF
115,750 FT	56-0760	19 Nov 1963	Maj R. W. Smith, USAF
114,400 FT	56-0760	14 Nov 1963	Maj R. W. Smith, USAF
113,087 FT	56-0760	19 Nov 1971	Maj D. F. Vikan, USAF
113,000 FT	56-0760	18 Dec 1964	Maj R. W. Smith, USAF
112,300 FT	56-0760	05 Dec 1963	Maj R. W. Smith, USAF
112,000 FT	56-0760	30 Nov 1964	Maj R. W. Smith, USAF
110,500 FT	56-0760	06 Dec 1963	Col C. E. Yeager, USAF
110,000 FT	56-0760	09 Dec 1963	Col C. E. Yeager, USAF

Table 2. 12 Highest NF-104A Rocket-Powered Zooms

C. Hangar Queen Phase

It would be another three years before the NF-104A would finally see service in the ARPS. From March 1965 to April 1967, the pair of remaining NF-104A aircraft (i.e., 56-0756 and 56-0760) took on the haunting role of Hangar Queen. A combination of USAF politics, ARPS apathy, and technical problems led to the most dismal period of the NF-104A program. A number of instructor pilots (IP's) were checked-out in the aircraft during this period and several times the NF-104A was very close to seeing ARPS service. However, hardware or system problems would appear at inopportune times to prevent introduction of the aircraft into the ARPS flying curriculum. These occurrences only seemed to reinforce an institutional hesitancy to move forward with the NF-104A.

Problems with the hydrogen peroxide oxidizer were by far the most exasperating and persistent plaguing the program. Recall that the hydrogen peroxide used by the NF-104A was 90-percent concentration by weight. This substance was extremely volatile and reacted with just about anything with which it came in contact. Reactions with impurities in the stainless steel oxidizer tanks and lines were the most critical issues. Leaks were a problem too in that the hydrogen peroxide would tend to pool in the lower portion of the airframe, damaging anything it touched. (See Figure 26.) Several onboard explosions occurred that caused sizable damage to the remaining NF-104A aircraft. Borrowing from NASA's X-15 experience, the SUMMA plating process was employed to finally overcome these difficulties. This process involved electropolishing the stainless steel oxidizer system components to make them chemically inert to hydrogen peroxide. Finally, aircraft maintenance personnel handling the substance had to wear protective clothing and a fireman's hood to protect themselves from hydrogen peroxide contamination. As an additional safety measure, the NF-104A pad area was constantly purged with water during servicing in order to dilute inadvertent hydrogen peroxide spills.


Figure 26. NF-104A Hydrogen Peroxide Damage

D. Return-to-Flight (RTF) Phase

The period of April 1967 to June 1968 marked a time of renewal for the NF-104A program. Zoom flight training in standard F-104A and F-104B aircraft (later, F-104C and F-104D, respectively) had continued to take place since the type's introduction into the TPS/ARPS flying curriculum back in the early 1960's. These aircraft were powered by the J-79 turbojet (i.e., no rocket augmentation) and typically zoomed to altitudes between 80,000 and 90,000 feet. However, the time was right to finally get the NF-104A ready and inserted into the ARPS flying curriculum. The driving force behind this effort was USAF Major James G. Rider, a former ARPS student (Class 65-C) and then-current staff instructor pilot. Rider worked with the Lockheed-California Company (LCC) and other ARPS staff members to get the aircraft back in the air. Working closely with Major Rider would be the LCC Technical Representative for the NF-104A, Alfred B. Christopher. History records that these two men were most responsible for returning the NF-104A to flight. In fairness though, there were other significant contributors at ARPS including: Major James M. Rhodes, Jr. (Class 66-A), Major Warwick H. Glasgow (Class 65-C), Major Fred R. Dent, III (Class 65-A), and Major Ronald W. Yates (Class 66-B). Together, this dedicated team developed and tested the procedures and techniques that would finally allow the NF-104A to fulfill its destiny as the ARPS capstone flying experience.

E. ARPS Phase

Captain J. Michael Loh (Class 67B) became the first ARPS student to fly an NF-104A rocket-powered zoom on 13 June 1968. Loh flew A/C 56-0756 to an altitude of 93,000 feet. Approximately 50 students from ARPS Classes 67-B through 71-A would fly the NF-104A over the next 42 months. Note that the privilege of flying the NF-104A was reserved for those who had done particularly well in the ARPS experience. As summarized in Table 3, at least 70 men (inclusive of project, evaluation, ARPS staff, and ARPS student pilots) have been verified by the author as having flown the aircraft in a rocket-powered zoom. Typical zoom apex altitudes were on the order of 106,000 feet. Although some 3 miles lower than Major Robert W. Smith's highest zoom apex altitude (120,800 feet) of 06 December 1963, the NF-104A nevertheless did provide many of the benefits originally intended by the ARPS staff back in 1961.

Class 67B	11
Class 68A	3
Class 68B	6
Class 69A	6
Class 69B	9
Class 70A	10
Class 70B	6
Class 71A	4
ARPS Staff	12
Project Pilots	2
Evaluation Pilot	1
Total	70

Table 3. NF-104A Pilots

The NF-104A flight training regimen prepared the novice NF-104A pilot well for the ultimate experience of a rocket-powered zoom. The initial training included (1) 4 hours in an F-104C flight simulator followed by (2) a pressure suit familiarization flight in an F-104C as well as (3) a zoom familiarization flight with an instructor pilot in an F-104D. Intermediate training included a return to the F-104C flight simulator for 4 hours of practice and instruction followed by 3 non-rocket zoom flights in an F-104C. The final ground training occurred in the NF-104A flight simulator where the student was provided with 4 hours of practice and instruction as a tune-up for the real thing. The test pilot student was then provided with two opportunities to fly the NF-104A in a rocket-powered zoom. Typically, this included target inertial pitch angles of 30 degrees and 45 degrees with a mission total elapsed time on the order of 30 minutes.

On 20 December 1971, Major Ralph H. Graham (Class 71-A) became the last ARPS student to fly the NF-104A on a rocket-powered zoom mission when he took A/C 56-0760 to an altitude of 100,200 feet.[19] Moreover, A/C 56-0756 had been permanently grounded since June of that year due to rudder and aft fuselage damage caused by an inflight explosion of the LR 121-NA-1 rocket motor.[20] The NF-104A program was now over and the aircraft would never again grace the skies over Edwards Air Force Base. Changing national priorities also made it apparent that the air force would not be sending anyone into space aboard air force spacecraft after all. (Other than Apollo 17 in December 1972 and the Apollo-Soyuz mission in July 1975, NASA would not be sending astronauts into space until the first flight of the Space Shuttle in April of 1981.) Thus, the USAF Aerospace Research Pilot School (ARPS) was redesignated as the USAF Test Pilot School (TPS) on 01 July 1972. In late 1973, USAF Captain Henry D. Hoffman III (Class 73-A) flew the final F-104C non-rocket zoom in the TPS pilot training program.[21] The F-104 was then officially retired from TPS service. These events brought to a close 12 years of flight test training using the venerable F-104 aircraft at Edwards Air Force Base.

VII. NF-104A AST Retrospective

The NF-104A was in reality a hybrid aircraft-spacecraft which afforded pilots with a unique opportunity to experience aerodynamic and space-equivalent flight during the same mission. It was a demanding airplane to fly in terms of achieving maximum zoom performance. The pilot had to intercept the target inertial pitch angle early in the pull-up and maintain it as long as possible. Once this angle started coming down, this usually meant that the flight path angle was also decreasing. And once lost during the climb, flight path angle was virtually impossible to regain, which had a direct bearing on the ultimate altitude achieved on a given flight. Good stick and rudder skills alone were not sufficient in extracting this performance from the vehicle. The pilot had to also understand and apply the principles of space mechanics to properly control the NF-104A flight path and inertial attitude. Especially imperative was the necessity to control the aircraft angle-of-attack near the zoom apex and preparatory to reentry. Failure to do so would always result in less than desired altitude performance and could (and did on one occasion) lead to loss of aircraft. A well-known adage among pilots avers that one must always stay ahead of the airplane and this was certainly never more true than in the NF-104A. The author has interviewed most of those who flew the airplane in a rocket-powered zoom and the collective testimony of that select group of pilots is that this particular mission was the busiest time they ever spent in the cockpit. Finally, mission planning and preparation were essential to flying an optimal zoom in the NF-104A. This included an accounting of how atmospheric temperature and wind variations along the zoom flight trajectory would affect altitude performance.

The NF-104A still holds the distinction of having achieved the highest altitude from a runway take-off for an United States aircraft. Specifically, USAF Major Robert W. Smith zoomed A/C 56-0760 to an altitude of 120,800 feet on Friday, 06 December 1963. This mark was very nearly the theoretical maximum capability of 125,000 feet. On the subject mission, target pull-up Mach number, inertial pitch angle, and angle-of-attack were 2.35, 70 degrees, and 15 degrees, respectively. Dynamic pressure at the zoom apex was approximately 2 PSF. The aircraft mishap of 10 December 1963 forever changed the way in which the NF-104A would be allowed to fly the rocket-powered zoom mission. Maximum altitude was subsequently limited to around 108,000 feet by restricting maximum pull-up Mach number, target inertial pitch angle, angle-of-attack, and apex minimum dynamic pressure to 2.15, 50 degrees, 8 degrees, and 20 PSF respectively. This restricted performance was mandated ostensibly out of concern for ARPS student pilot safety. It is indeed true that the vast majority of those who went on to fly the NF-104A at ARPS claim that the spaceflight training experience they received thereby was the literal and figurative pinnacle of their flying careers. Nonetheless, the ultimate and lasting result of the flight performance restriction was that it did a great disservice to ARPS student test pilots in that it made their spaceflight training experience something less than what it could and should have been. It is ironic that, although the correct manner in which to zoom the airplane had been repeatedly validated prior to the 56-0762 mishap, the decision to restrict NF-104A performance was based on a single flight which clearly demonstrated how not to fly the aircraft. In that regard as well as others, there is much to the NF-104A story that has not and cannot be told here. Suffice it to say that the author is in the process of writing a detailed aviation history that more fully relates the unique story of the NF-104A Aerospace Trainer.

References

[1]Dorr, Robert F., F-15 Eagle, *World Airpower Journal*, Volume 9, Summer 1992.

[2]Urschel, Peter H. and Cox, Timothy H., "Launch Condition Deviations of Reusable Launch Vehicle Simulations in Exo-Atmospheric Zoom Climbs", NASA/TM-2003-212023, September 2003.

[3]TPS Chronicle Staff, *United States Air Force Test Pilot School History (1944-1979)*, Air Force Flight Test Center (AFFTC), Edwards Air Force Base, 1979, p. 47.

[4]TPS Chronicle Staff, *United States Air Force Test Pilot School History (1944-1979)*, Air Force Flight Test Center (AFFTC), Edwards Air Force Base, 1979, p. 46.

[5]Morrison, W. H., Rocket-Boosted Lockheed Starfighter Trains Astronauts For Space Mission, News Bureau, Lockheed California Company, 26 December 1968.

[6]AFFTC History Office Staff, History of the Air Force Flight Test Center (01 January-30 June 1965), AFSC Historical Publications Series, United States Air Force, Air Force Systems Command, Air Force Flight Test Center, Edwards Air Force Base, June 1965, p. 129.

[7], C. M., "Space Training Flights in NF-104A Near", *Aviation Week and Space Technology(AWST)*, 09 August, 1965, pp.80-85.

[8]Flight Test Engineering Staff, "NF-104A Aerospace Trainer Flight Test Program Summary", LR 17450, 13 December 1963.

[9]Hendrickson, Clendon L. and Smith, Robert W., "NF-104A Aerospace Trainer Evaluation", FTC-TR-65-37, December 1965.

[10]Smith, Robert W., "Partial Flight Manual Aerospace Trainer, NF-104A AF 56-0756 and 56-0760 Aircraft, T.O. 1F-104A-1-2, 01 January 1965.

[11]Staff Reporter, "Test Pilot Reaches New Altitude Record at Edwards", *The Edwards Flyer*, 21 November 1963.

[12]Horne, Richard G., "NF-104A Altitude Record Attempt", Headquarters, Air Force Systems Command, United States Air Force, Andrews Air Force Base, 10 October 1963.

[13]Research Staff, *Jane's All-the-World's Aircraft*, 1982-83 Edition, p. 207.

[14]Wood, James W., "NF-104A Major Aircraft Accident Report (S/N 56-0762)", United States Air Force, Air Force Flight Test Center, Edwards Air Force Base, 10 December 1963.

[15]Research Staff, *Jane's All-the-World's Aircraft*, 1985-86 Edition, p. 238.

[16]Staff Interviewer, "General Chuck Yeager Interview", Academy of Achievement: A Museum of Living History, Washington, D.C., URL: http://www.achievement.org/autodoc/page/yea0int-1 [cited 16 May 2005].

[17]Smith, Robert W., URL: http://www.nf104.com [16 May 2005].

[18]Air Force Flight Test Center History Office (AFFTC/HO); NF-104A Historical Records.

[19]Staff Reporter, "ARPS NF-104 Program Ends", *The Desert Wings*, Volume 16, Number 26, 23 December 1971.

[20]AFFTC History Office Staff, History of the Air Force Flight Test Center (FY 1972), AFSC Historical Publications Series, United States Air Force, Air Force Systems Command, Air Force Flight Test Center, Edwards Air Force Base, 1972, p. 201.

[21]TPS Chronicle Staff, *United States Air Force Test Pilot School History (1944-1979)*, Air Force Flight Test Center (AFFTC), Edwards Air Force Base, 1979, p. 105.