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Rocket Starflyer™: Modified NF-104 for Space Tourism

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At present there are many companies seeking to capitalize on the emerging market of space tourism. All of these companies are using clean sheet designs. This paper discusses an alternative approach of upgrading an existing and the seemingly forgotten airframe of the NF-104A. It is anticipated that this approach will lead to lower mission cycle costs, shorter turn around time, short development times and ultimately lead to a better all around business model.

I. Introduction

THE dream remains to access space for the casual tourist and to give them a ride that they both won't forget (boom and zoom) and to safely make money (investment). In the mid 1960's the F-104A was modified (becoming the NF-104A) fitted with a small rocket engine in the aft tail which enabled it to obtain an altitude of 120,000 ft. The proposed is to take the existing NF-104 design and upgrade the tail engine to longer run time and higher thrust thereby achieving "space" altitudes. The following sections provide information on the original fighter aircraft and on particular version modified to become what was called the rocket starfighter.

II. NF-104 History

The NF-104A was derived from the F-104A military aircraft which was designed for the express mission of high performance supersonic intercept.[1] As such the design implied high speed and high rate of climb and was the first aircraft to simultaneously hold the world records for speed, altitude and time-to-climb[2]. The initial production versions of the F-104A used the GE J79-GE-3B afterburning turbojet engine beginning in 1958[3]. The NF-104A, rocket starfighter was derived from the initial production version being modified for brief space flight. Highly interesting and informative historical accounts of the NF-104A are to be found in references 4 & 5, a synopsis of which is given below.

A. The F-104A Aircraft[1-2, 6]

The F-104A was introduced in to US service in 1958 as a single seat aircraft. The aircraft was very successful and was eventually adopted by the air services of fifteen (15) countries, which included a total of 2578 manufactured aircraft. The Lockheed Aircraft Company F-104 production also included 17 different variations of which 325 units were of the two seat variants (See Figure 1). The US eventually retired the F-104 family from service in 1975 from the Air National Guard. The last country to retire the F-104 airframe was Italy in 2004 however many F-104s are being flow privately throughout the world by enthusiasts. The F-104A weights 13,184 pounds dry with a wingspan of 21 feet 9 inches, a length of 54 feet 8 inches and has the appearance of a dart. The powerplant was a single GE J79-GE-3B producing 9,600 lbf of thrust dry and 14,800 lbf of thrust with afterburners. In 1959 this initial version of the aircraft was able to climb to an altitude of 91,245 ft "as built".

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B. Conversion & Use of NF-104A[3-5,7]

In 1961 Lockheed California Company (Burbank, CA) was issued a contract to convert three (3) F-104A aircraft into the NF-104A (Rocket Starfighter) configuration. In simple terms the modifications permitted the existing F-104A design to fly higher in altitude using thrust from a rear mounted rocket engine and smaller rocket engines to provide roll, pitch and yaw control at altitudes where aerodynamic control no longer existed (the resultant aircraft is shown in Figure 2). More specifically the modifications included:

- Combat gear stripped including wingtip tank capability.
- Larger tailfin, J79-GE-3B with longer double shock intake cones.
- Rocketdyne built AR2 (LR121) pump fed throttleable liquid rocket engine using 90% hydrogen peroxide & jet fuel mounted in the tailfin. The maximum thrust approximately 6000 lbf at altitude.
- Metal nose with pitch and yaw thruster using 90% hydrogen peroxide.
- Larger wings (2 feet each side) with roll thrusters using 90% hydrogen peroxide.
- Hydrogen peroxide feed systems including tankage, etc.
- New radio, avionics and pilot fitted with full pressure suit.

Using this set of equipment the NF-104 used the zoom maneuver (where a pilot trades kinetics energy for potential energy enabling the aircraft to reach altitude beyond the normal operating envelope) to consistently achieve peak altitudes of 110,000 ft. The zoom profile is shown in Figure 4 and as can be seen the kinetics energy portion of the profile occurs above 35,000 ft where the rocket is used to supplement the air breathing engine. The pull-up occurs at a little over Mach 2.2-2.4 and 3.5-4.0 gs and relies primarily on rocket propulsion for the remainder of the accent. Figure 5 shows the NF-104 in rocket powered flight at approximately the 70 degree accent angle used to obtain maximum altitude. Figure 6 shows Robert W. Smith climbing into the NF-104A on December 06, 1963 just before the record maximum altitude obtained by a NF-104A of 120,800 ft. Note that the record flight occurred on *the same day and with the same aircraft* after Charles Yeager made a rocket flight to 94,500 ft, showing the versatility and short cycle time of the NF-104A vehicle.

One of the three aircraft crashed with Charles Yeager piloting on December 10, 1963. Subsequent to the crash the permitted envelope was reduced and was flown from 1965 to 1971 for 70 more flights. The remaining two NF-104A aircraft were retired at that time. One of the two surviving aircraft is on display at the Edwards AFB flight test school entrance and the author is unaware of the whereabouts of the second vehicle. Over the entire NF-104A program a total of 302 flights were performed accumulating 8.6 hours of rocket on time.

III. Rocket Starflyer Inc.

There has been a great deal of interest in space tourism in the last decade especially with the advent of the X-prize and the subsequent capture by Scaled Composites. The X-Prize required flights above 328,000 ft which is roughly the 100 km requirement to be considered "space flight" by the Federation Aeronautique Internationale. The NF-104A as it was configured and flow in the 1960s is about 205,000 ft short (roughly 1/3) of the "space flight" requirements. It is the authors supposition that the NF-104 altitude envelope can be greatly enhanced perhaps even to 328,000 ft by use of existing modern equipment. Robert W. Smith notes in his online history of the NF-104 that: "By replacing the AST with much more modern but existing components it seems possible to go more than twice my 121,800 [sic] record carrying in its bay a one stage rocket to place a satellite into earth orbit"[4]. Hence a modern version of the NF-104 even if it would not achieve 328,000 ft would still provide a viable business plan with some potential markets being:

- Sub-Orbital Space Tourism – Price Ladder for Lower/Upper Altitudes
- Space Nostalgia Tourism – *The Right Stuff*
- Private Spaceplanes (Sport Planes)
- Astronaut Training, Rocketplane Training
- US Gov R&D: NASA, USAF, DARPA
- Upper Atmospheric Measurements: Weather, Shuttle Winds Aloft, etc.
- Picosat Class (< 1 Kg) Launch Vehicle
- Military Strike System

Consequently the following loose business plan is proposed which would provide the lowest cost and fastest method of obtaining access to such markets. The plan includes formation of a new company (Rocket Starflyer Inc.™) which would control the program management, flight operations, vehicle maintenance, sales & marketing and control the intellectual property. In order to minimize risk and reduced time to revenue the first step in the business plan would be to bring the NF-104A back to life in "as close as possible" condition. It is understood that many of the subsystems may not exist anymore or it may be impractical to use outdated technology. It is envisioned that the Rocket Starflyer Inc.™ company would only require two major subcontractors: Lockheed (whose major subcontractor would be the air breathing engine company) and General Kinetics (for the rocket engines). The following sections describe the subcontractors' roles and some of the technology. The general idea would be to bring the NF-104A back to life with a philosophy of as close as possible to replicating. Then once the vehicle has been replicated and flying it can begin to generate income while the envelope is expanded in a given direction with a specific customer need.

The Lockheed Skunkworks would act as airframe integrator and would probably need to uncover some of the original work that the original Lockheed California Company performed. As such they probably still have access to the original tooling or drawings. Because the F-104 was produced in such quantity there should are plenty of airframes which can be purchased for minimal cost and providing a great deal of spare availability. It is also anticipated that the ruminants of the prior two NF-104 aircraft can be used for reverse engineering provided that they are not harmed in the process. Additionally, the later versions of the F-104, in particular the F-104G (1,122production units) used a higher performing J79-GE-11A jet engine with 4.2% and 5.4 % thrust performance increase (dry, with afterburners) compared to the original engine. On top of that major advances have been made in jet engines since the original NF-104 engine. As an example the Pratt & Whitney F100-PW-229 has a 85% and 97% thrust performance increase (dry, with afterburners) with roughly the same dimensional envelope and slightly smaller mass that the original J79-GE-3B[1,6,16]. This increase in air breathing performance would allow the vehicle to delay the point of turning on the rocket engines thereby saving the propellant mass for flight periods when it is needed most. Additionally, mass injection of water or hydrogen peroxide would permit the air breathing engine to operate at even higher altitudes. Hence this option would also permit delaying use of the rocket engine. It is envisioned that there would be a version which would not use rocket assist but still would readily fly to 100,000 ft and require hydrogen peroxide roll, pitch and yaw thrusters. This is certainly an intermediate configuration that was probably used during the initial development phase of the NF-104 (see Figure 4).

General Kinetics Inc. would be responsible for the rocket portion of the modifications to the NF-104 having the greatest modern experience with hydrogen peroxide combustion devices. The hydrogen peroxide rocket modifications would be comprised of three basic portions: The hydrogen peroxide feed system, the monopropellant roll, pitch and yaw rockets and the hydrogen peroxide – kerosene bi-propellant tail mounted aft rocket engine. The original hydrogen peroxide system on the NF-104A was primarily made of 300 series stainless steel. This material is good for short term storage (1 week at 70 F or 4 hours at 140 F) if properly treated and passivated. I appears from reading some of the historical records that the material may not have been completely passivated properly. Verification of proper passivation procedures on stainless steel would be conducted with modern techniques. Additionally, there are now many modern materials which would provide indefinite storage of the hydrogen peroxide with perhaps even reduced feed system mass. This would be an obvious upgrade which would help with reduce sortie turn around time. Additionally, for increased altitude flight operations the rocket engine will need to operate for longer periods of time. Hence, one of the first system upgrades will be to increase the hydrogen peroxide storage capacity which would include the use of modern compatible materials. The only modern manufacturer of flight worthy hydrogen peroxide devices is General Kinetics. Hence there are off the shelf monopropellant thrusters which would be used for the roll, pitch and yaw thrusters. Figure 8 shows just such a monopropellant thruster using 90% hydrogen peroxide which produces 150 lbfv of thrust (NF-104A used 43 lbf roll and 113 lbf pitch/yaw thrusters). This thruster was developed for high performance and operates at a proven power density 3 times better than prior state of the art in the 1960s[9]. Hence the thruster volume and mass are better than the previously used devices. General Kinetics has also been active in most all modern hydrogen peroxide bi-propellant rocket engine developments. The thrust level of these development engines have between 100 and 40,000 lbfv. In addition General Kinetics owns the only existing LR-40[10] man rated pump fed bi-propellant rocket engine. This engine is shown in Figure 9 and it outperformed the original NF-104A rocket engine in top end thrust (70% more), dry mass and reduced net positive suction head. Hence all of these factors would contribute to improved performance.

Although other companies are also pursuing space tourism vehicles these systems are clean sheet vehicles. It is the authors' experience that new and complicated systems often run into technical challenges that cause cost escalation and delay. Both of which become very hard to overcome from a financial return standpoint. Hence this is why the "as close as possible" vehicle would be built first. And then modifications would be added as the market dictated. Table 1 shows the *actual* vehicle costs for the NF-104 along with another well known rocket based flight vehicle. The costs were escalated to 2006 dollars using the US consumer price index. Although the two vehicles were very different in mission (X-15 peak altitude and speed much greater) and quantity build (the NF-104 actually drawing on several hundred production run of the F-104A) the price differences are quite large. Additionally note that the NF-104 conversion took place in about 1 year and the X-15 development took around 5 years. This data should also provide some reference pricing data that can be used to referee against proposed "clean sheet" designs.

Table 1 Actual Flight Vehicle Cost Comparison in Lot of Three – Escalated to 2006 Prices[1, 11]

	X-15 Price (2006 $)	NF-104 Conversion Price (2006 $)
Vehicle	$63M/X-15	$23M/NF-104
Operations	$3M/Flight	$10k/Flight
Development	$500M/X-15	Included in Vehicle

Initial business operations would specifically focus on identification of available components, identification of potential customers and their needs, trajectory analysis to identify mission options in conjunction with vehicle configurations. During the initial phase contacts and negotiations would begin with key subcontracts and possibly key assets would be purchased. Given that so many aircraft were built and in service in so many countries it is likely that there will be no shortage of pilots.

IV. Conclusion

The successful history of NF-104A rocket starfighter has been reviewed. The authors propose bringing the NF-104 back to life under the company name of Rocket Starflyer™ as a viable business plan for the following reasons:

- Viable and proven rocket spaceplane up to altitudes of 120,000 ft.
- Might be possible with modern technology and methods to push the flight envelope up to 328,000 ft.
- Should be capable of responsive deployment of pico-satellites and various space tourism missions.
- Proven low costs associated with development and operations.
- Proven sortie turn around time of several hours.
- Vehicle look combined with Boom & Zoom flight profile has the extremely "cool" feel for space tourism.

References

[1]Wikipedia, "F-104 Starfighter", URL: http://en.wikipedia.org/wiki/F-104_Starfighter [cited June 08, 2007].

[2]GlobalSecurity.org, "F-104 Starfighter", URL: http://www.globalsecurity.org/military/systems/aircraft/f-104.htm [cited June 12, 2007], 2000-2007.

[3]"Starfighter Origins/F-104 In USAF Service", URL: http://www.vectorsite.net/avf104_1.html [cited June 8, 2007].

[4]Smith, Robert W., "The history of the NF-104 AST by its primary test pilot Lt. Col. Robert W. Smith USAF (ret.)", URL: http://www.nf104.com [cited June 8, 2007], 1997-2007.

[5]White, John Terry, "Boom and Zoom: The History of the NF-104 AST", 41st AIAA Joint Propulsion Conference and Exhibit, AIAA-2005-3537, Tucson, AZ, July 2005.

[6]"Lockheed F-104A Starfighter", URL: http://home.att.net/~jbaugher1/f104_3.html [cited June 21, 2007], Nov. 26, 2002.

[7]Sarigul-Klijn, Marti and Sarigul-Klijn, Nesrin, "Flight Mechanics of Manned Sub-Orbital Reusable Launch Vehicles with Recommendations for Launch and Recovery", AIAA 2003-0909 (Revised September 2003), URL: http://mae.ucdavis.edu/faculty/sarigul/AIAA_2003_0909_revised_Sep03.pdf [cited June 10, 2007], 2002.

[8]General Kinetics Inc., "Product Catalog", URL: http://www.gkllc.com [cited June 8, 2007].

[9]Wernimont, Eric J. and Durant, Dick, "State of the Art High Performance Hydrogen Peroxide Catalyst Beds", 40th AIAA Joint Propulsion Conference and Exhibit, AIAA-2004-4147, Ft. Lauderdale, FL, July 2004.

[10]Ventura, Mark C. and Wernimont, Eric J, "History of the Reaction Motors Super Performance 90% H2O2/Kerosene LR-40 Rocket Engine", 37th AIAA Joint Propulsion Conference and Exhibit, AIAA-2001-3838, Salt Lake City, UT, July 2001.

[11]Love, James E. and Young, William R., "Survey of Operation and Cost Experience of the X-15 Airplane as a Reusable Space Vehicle," NASA TN D-3732, NASA Washington DC, Nov. 1966.

[12]Luijkx, Harry, "Homepage dedicated to the Famous Lockheed F104 Starfighter – History and Photographs of the Plane", URL: http://www.starfighters.nl [cited June 8, 2007], 1995-2007.

[13]The X-Hunters, "Lockheed NF-104A AeroSpace Trainer", URL: http://www.thexhunters.com [cited June 11, 2007], 2004-2007.
[14]NASA Dryden, "F-104A Starfighter Photo Collection", URL: http://www.dfrc.nasa.gov/Gallery/Photo/F-104/Large/index.html [cited June 21, 2007], Oct. 6, 2006.
[15]"NF-104 Space Pilot Trainer", URL: http://www.batnet.com/mfwright/nf104.html [cited June 21, 2007], Dec. 4, 2004.
[16]Wikipedia, "Pratt & Whitney F100", URL: http://en.wikipedia.org/wiki/Pratt_&_Whitney_F100 [cited June 12, 2007].

Figure 1. Two Seat Version F-104, Likely an F-104J[12]

Figure 2. NF-104 Rocket Starfighter (Note the Rocket Tailpipe just above the Jet Engine Exhaust)[13]

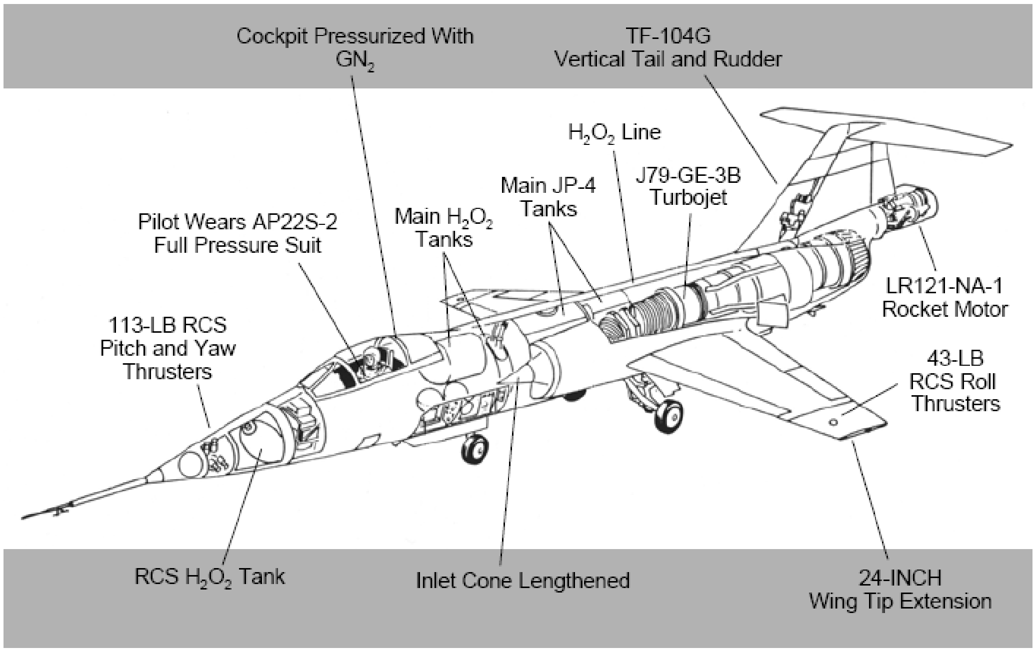

Figure 3. Rocket Starfighter Layout Noting Most of the Conversion Components for a NF-104A[5]

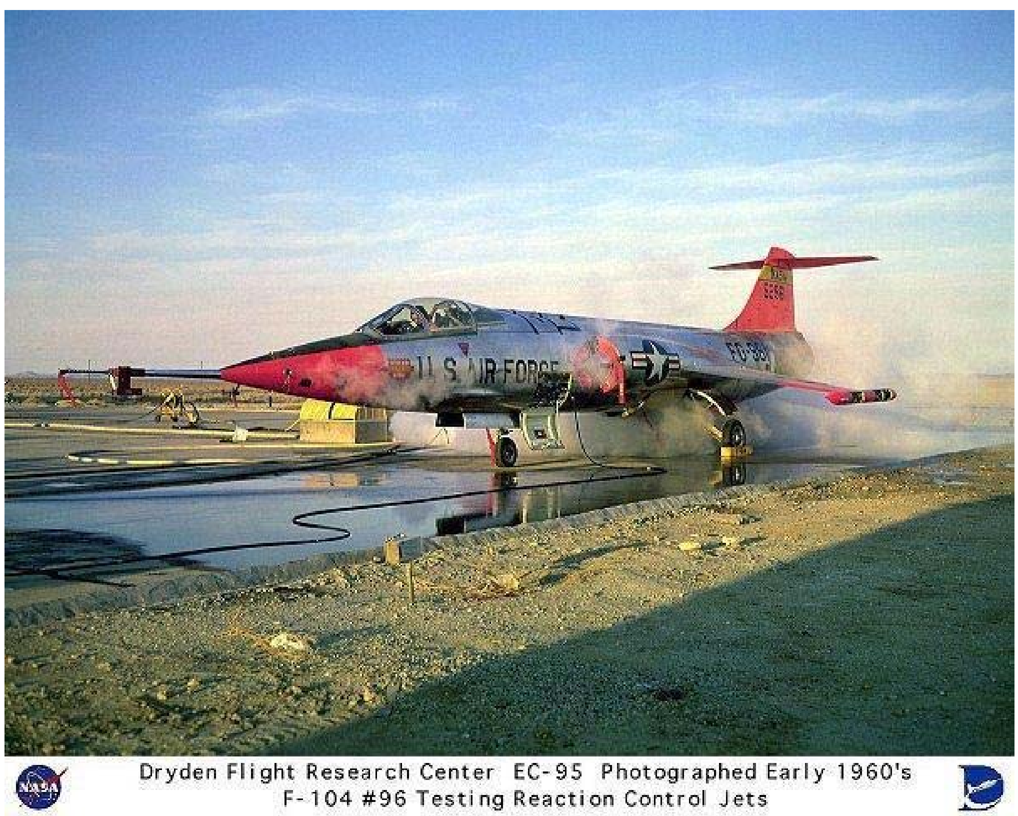

Figure 4. JF-104A (Formerly YF-104A) was Modified with Hydrogen Peroxide Reaction Control System (RCS). Following a Zoom Climb to Altitudes in the Vicinity of 80,000 ft, the RCS Gave Controllability in the Thin Atmosphere Where Conventional Control Surfaces Are Ineffective[14]

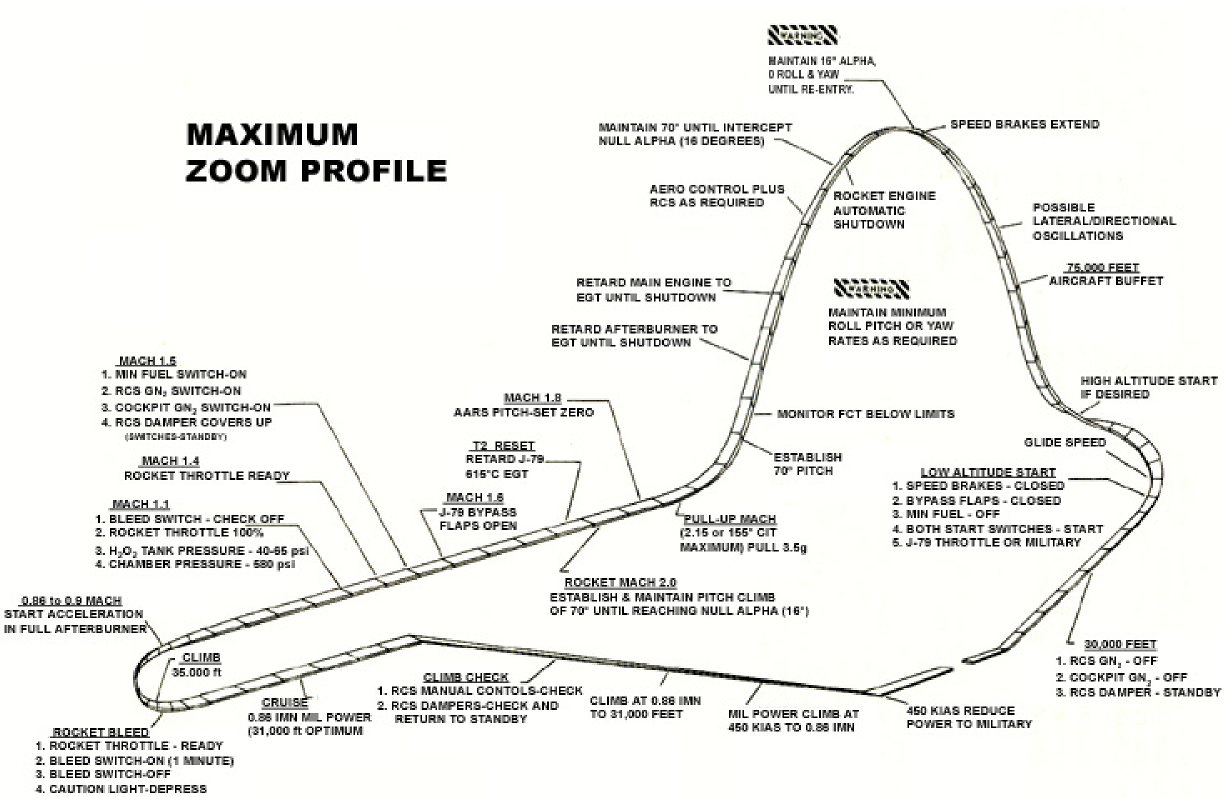

Figure 5. NF-104 Rocket Starfighter Zoom Maneuver Flight Trajectory[4]

Figure 6. NF-104A Rocket Starfighter during Rocket Powered Flight[15]

Figure 7. Major Robert W. Smith Climbing into NF-104A Before Record Flight to 120,800 ft[4]

Figure 8. General Kinetics 150 lbfv 90% Hydrogen Peroxide Monopropellant Thruster – More Than 3 Times More Power Dense than Prior State of the Art from 1960s[9]

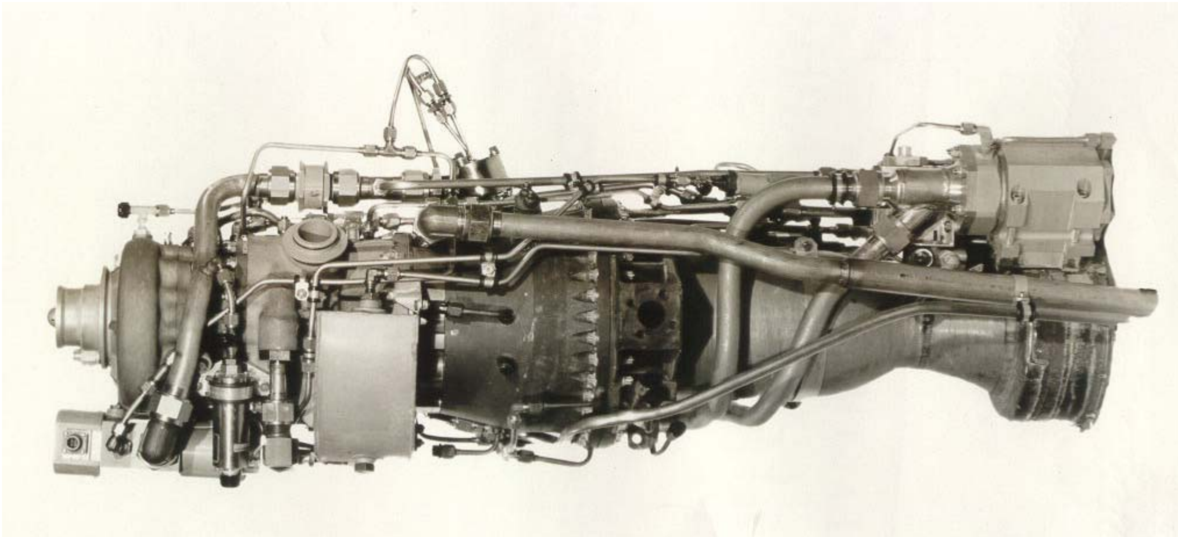

Figure 9. General Kinetics Owned Man Rated LR-40 10,200 lbfv 90% Hydrogen Peroxide/Kerosene Bi-Propellant Pump Feed Rocket Engine – 70% more Thrust than Original NF-104 Rocket Engine and Lighter[8, 10]