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Abstract

The three-stage Taurus-Nike-Tomahawk launch vehicle is being considered for performance enhancement of the existing Taurus-Tomahawk flight system. In addition, performance enhancement of other existing two-stage launch vehicles is being considered through the use of tandem booster systems. Aeroballistic characteristics of the proposed Taurus-Nike-Tomahawk vehicle are presented, as are overall performance capabilities of other potential three-stage flight systems.

Introduction

The NASA Sounding Rocket Program provides a means for conducting Space Science and Applications research in the near-earth environment. A number of suborbital rocket vehicle systems are currently used for this purpose (Table I).

The majority of Upper Atmosphere and Plasma Physics research is attained through the use of the Tomahawk (9-inch diameter), Orion (14-inch diameter) and Malemute (16-inch diameter) flight systems. Accordingly, the majority of Solar and Astronomy research is attained using heavier payloads flown on Black-Brant (17.25-inch diameter) flight systems with the very heavy, large diameter payloads in these disciplines being flown on the boost-guided Aries vehicle.

In recent years, experimental requirements have been expressed for scientific measurements at the higher altitudes--i.e. above 600 km--particularly in the Plasma Physics discipline. In 1978, the cost effective Taurus-Tomahawk system was developed to help satisfy the higher altitude requirement for lightweight payloads (60-80 lb).¹ More recently, the Black Brant X three-stage system has been developed to provide 1,000 kilometers-plus altitude capability.

TABLE I -PRIMARY NASA SOUNDING ROCKETS

TOMAHAWK FAMILY	9 IN. PRINCIPAL DIAMETER
NIKE-TOMAHAWK	
TAURUS-TOMAHAWK	
ORION FAMILY	14 IN. PRINCIPAL DIAMETER
ORION	
NIKE-ORION	
TAURUS-ORION	
MALEMUTE FAMILY	16 IN. PRINCIPAL DIAMETER
NIKE-MALEMUTE	
TERRIER-MALEMUTE	
BLACK BRANT V FAMILY.	17.26 IN. PRINCIPAL DIAMETER
BLACK BRANT V	
NIKE-BLACK BRANT V	
TERRIER-BLACK BRANT V (BLACK BRANT IX)	
TERRIER-BLACK BRANT V - NIKKA (BLACK BRANT X)	
ARIES (BOOST GUIDED).	44.3 IN. PRINCIPAL DIAMETER

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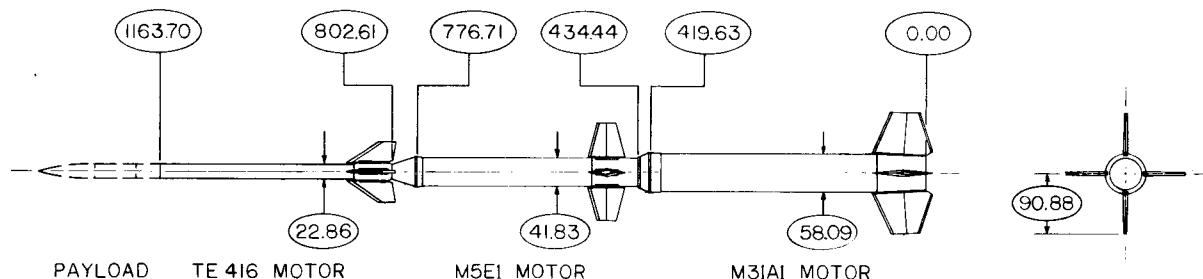
Since its development, the Taurus-Tomahawk vehicle has been successfully utilized for the ten flight missions detailed in Table II. The original chemical release payload flown on the Taurus-Tomahawk launch vehicle was relatively short and lightweight (42 inches long, approximately 60 pounds). The apogee performance capability with these payloads has been in excess of 550 km. A new class of chemical release payloads with added scientific instrumentation have been designed and are currently being flown on the Taurus-Tomahawk. With the greater weight of the new payloads (115-120 pounds) the apogee capability has dropped by approximately 100 km. Also, the length of these payloads are approaching the 70-inch maximum limit for the Taurus-Tomahawk (due to aeroelastic stability considerations). In order to enhance the performance capability of the Tomahawk flight system, consideration has been given to the feasibility of utilizing a three-stage vehicle composed of a tandem booster system.

Taurus-Nike-Tomahawk

The proposed tandem booster system to be used with the performance-enhanced Tomahawk vehicle is composed of the Taurus (Improved Honest John M31A1) rocket motor as the first stage with the Nike (M5E1) rocket motor as the second stage. Launch configuration for the proposed Taurus-Nike-Tomahawk vehicle is shown in Figure 1. The Nike motor is easily adapted to the Taurus through the use of the existing Taurus forward adapter (used on Taurus-Orion and Taurus-Tomahawk vehicles) and a standard Nike-Nike interstage. The Nike-Tomahawk adapter would be modified to include a clamp system and associated electronics to prevent premature drag separation of the second and third stages. The timed release of the clamp would allow drag separation to occur at second stage burnout.

TABLE II - TAURUS-TOMAHAWK LAUNCH HISTORY

<u>VEHICLE NUMBER</u>	<u>PAYLOAD WEIGHT</u>	<u>LAUNCH DATE</u>	<u>LAUNCH RANGE</u>
12.1005 WT	62.3 lbs.	10-31-78	WI
12.1003 UE	61.7 lbs.	03-23-79	PFRR
12.1004 UE	62.1 lbs.	04-01-79	PFRR
34.001 UE	60.9 lbs.	03-19-80	PFRR
34.002 UE	59.7 lbs.	03-22-80	PFRR
34.003 UE	69.3 lbs.	03-16-80	PFRR
34.004 UE	59.7 lbs.	04-01-81	PFRR
34.005 UE	99.0 lbs.	03-25-81	PFRR
34.007 UE	57.25 lbs.	03-15-82	PFRR
34.008 UE	115.0 lbs.	03-30-82	PFRR



TAURUS - NIKE - TOMAHAWK (TNT) LAUNCH VEHICLE

DIMENSIONS IN CM

FIGURE 1

The Taurus first stage fin panels are modified from standard trapezoidal planform, diamond-profile booster fins used on the tactical Nike-Ajax anti-aircraft system. Each panel is trimmed at the tip, reducing exposed fin area from 5.7 ft² to 4.8 ft². Untrimmed panels could be used if needed for added stability with very light payloads. A M31A1 tactical nozzle shroud and fin-attach hardware are utilized, with the fins mounted in a cruciform configuration.

Second stage fin panels are Aerolab 2.5 ft² Nike fins with a capped leading edge. Due to the heavier fin panels, the fin/shroud assembly is approximately 30 pounds heavier than the standard NASA Nike booster cruciform fin/shroud assembly. The third stage fin/shroud assembly is standard Thiokol Tomahawk hardware; the fin panels have an exposed area of 1.85 ft² (266 in²) and are mounted in a cruciform arrangement, in-line with the first and second stage fins.

Predicted performance characteristics for the proposed Taurus-Nike-Tomahawk vehicle have been evaluated and are compared with Nike-Tomahawk and Taurus-Tomahawk performance capability in Figure 2. For the lighter payload weights, the Taurus-Tomahawk has approximately 100 km additional altitude capability over the Nike-Tomahawk. Likewise, the Taurus-Nike-Tomahawk vehicle has 200 km additional altitude capability over the Taurus-Tomahawk. It is obvious that the proposed three-stage system has 600-plus km altitude capability for a payload weight of 100 pounds at high launch elevation angles.

A limited aeroballistic analysis has been performed for the proposed Taurus-Nike-Tomahawk to establish the feasibility of the system as a high performance addition to the NASA stable of operational launch vehicles. Physical properties of the vehicle system (less payload) are summarized in Table III. For the aeroballistic parameters presented here, a payload with the following characteristics was assumed:

- length - 66 inches
- diameter - 9 inches
- nose shape - 3:1 ogive
- weight - 120 pounds
- center of gravity - 30 inches from base
- pitch moment of inertia - 5.5 slug-ft²
- roll moment of inertia - 0.26 slug-ft²

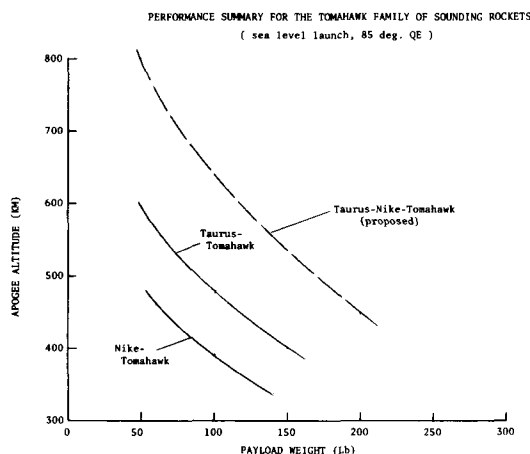


Figure 2 - Performance Summary for Tomahawk Vehicle Family

Flight performance characteristics were determined by using the NASA SG-GEM computer program. This program determines the flight trajectory of a vehicle in three-dimensional space, as it is acted upon by rocket motor thrust, vehicle weight and aerodynamic forces, relative to a rotating oblate spheroid earth. The results of the trajectory simulation, which assumes a launch elevation angle of 83° from a sea level site, can be found in Figures 3 through 6. Nike ignition

TABLE III - TAURUS NIKE TOMAHAWK PHYSICAL PROPERTIES (less payload)

Event	Nominal Time (Seconds)	Weight (Pounds)	C. G. (Inches)	C. G. Reference	IYY ² (Slug-ft ²)	IXX ² (Slug-ft ²)
Taurus Ignition	0.0	4916.00	167.739	Taurus NEP	12867.987	77.496
Taurus Burnout	3.515	3237.75	204.093	Taurus NEP	9731.173	53.876
Nike Ignition	8.0	1910.90	114.129	Nike NEP	2224.214	19.615
Nike Burnout	11.54	1155.90	136.002	Nike NEP	1837.627	14.815
Tomahawk Ignition	18.0	547.00	70.49	Tomahawk NEP	202.08	2.25
Tomahawk Ignition +2	20.0	451.00	71.74	Tomahawk NEP	174.56	2.11
Tomahawk Ignition +4	22.0	348.00	70.81	Tomahawk NEP	146.50	1.91
Tomahawk Ignition +6	24.0	252.00	66.55	Tomahawk NEP	121.63	1.70
Tomahawk Ignition +7	25.0	211.00	61.81	Tomahawk NEP	102.77	1.60
Tomahawk Ignition +8	26.0	174.00	52.42	Tomahawk NEP	80.73	1.47
Tomahawk Burnout	26.93	149.60	44.09	Tomahawk NEP	62.81	1.37

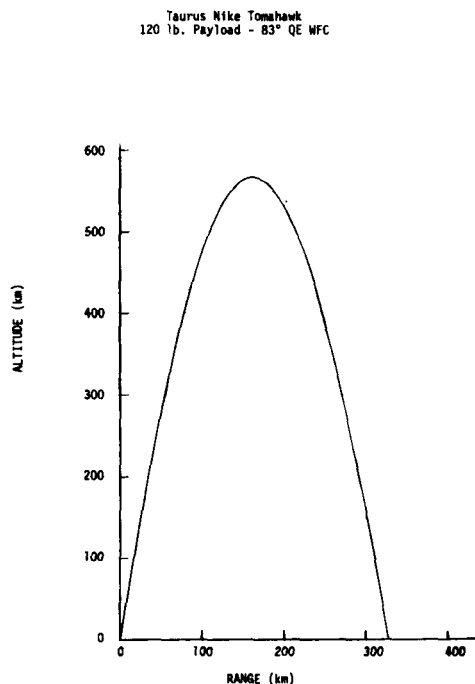


Figure 3 - Trajectory Profile

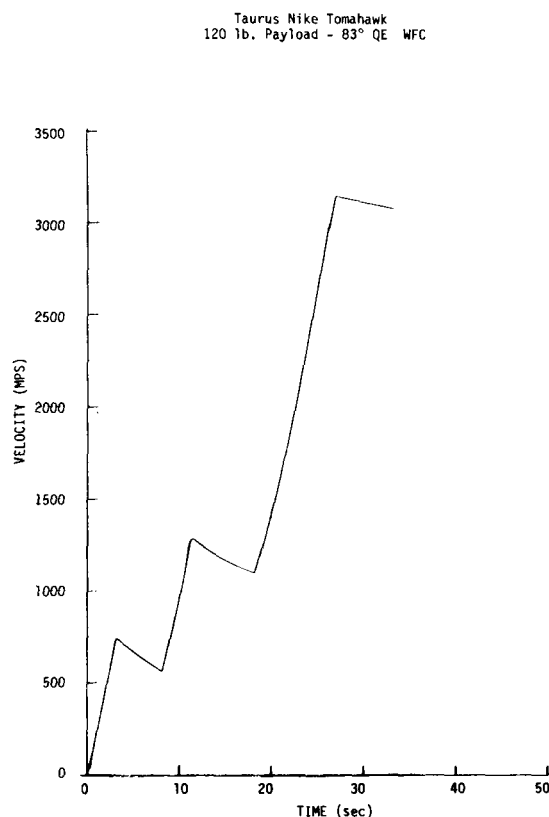


Figure 4 - Velocity vs. Flight Time

occurs at 8.0 seconds and Tomahawk ignition is set at 18.0 seconds. The apogee obtained is 566 kilometers with an impact range of 325 kilometers. The maximum Mach number of 10.3 occurs at Tomahawk burnout with a maximum dynamic pressure of 9,575 psf occurring near burnout of the second stage. This represents an increased apogee capability in excess of 100 kilometers over the Taurus-Tomahawk; and, while there is essentially no change in the expected maximum Mach number, the three-stage system offers a definite improvement in flight dynamic pressure. On the Taurus-Tomahawk, the maximum dynamic pressure occurring at Taurus burnout, would be approximately 14,000 psf.

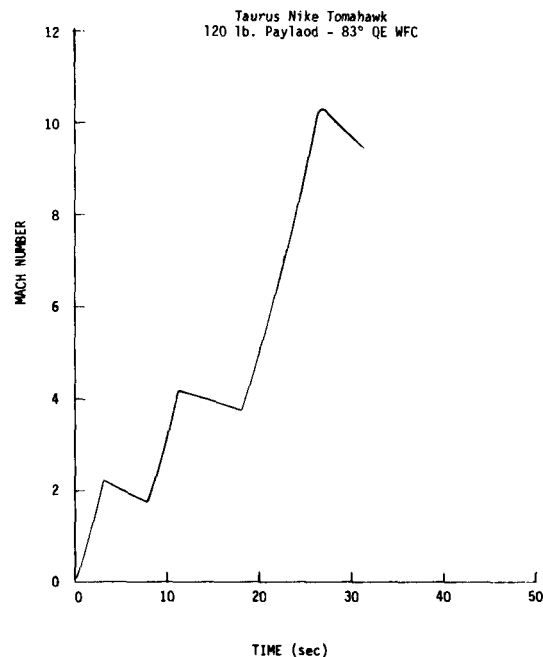


Figure 5 - Mach Number vs. Flight Time

Vehicle rigid-body and flexible-body stability characteristics have been examined. The degradation of vehicle rigid-body stability due to aeroelasticity was determined by using the NASA/GSFC FLMD-II computer program.² A 3.0 degree angle of attack was assumed at the time of maximum dynamic pressure during the burn phases for both the first and second stage motors. These represent the most critical points during the flight. Both the rigid and flexible-body centers-of-pressure and the mass center for this vehicle can be found in Figure 7. First stage rigid-body stability is 2.3 calibers (based on the Taurus diameter of 22.75 inches) at the time of maximum dynamic pressure. Flexible-body bending effects result in a 22% reduction in stability at that time to 1.79 calibers. The stability index, which is the ratio of the flight dynamic pressure to the dynamic pressure at which positive static stability ceases to exist, is 0.18. This is well below the accepted maximum limit of 0.5. The minimum stability margin which occurs at first stage ignition is only 0.92 calibers. By using unmodified Nike-Ajax fins, the center of pressure is moved aft, thus increasing stability at liftoff.

Taurus Nike Tomahawk
120 lb. Payload - 83° QE WFC

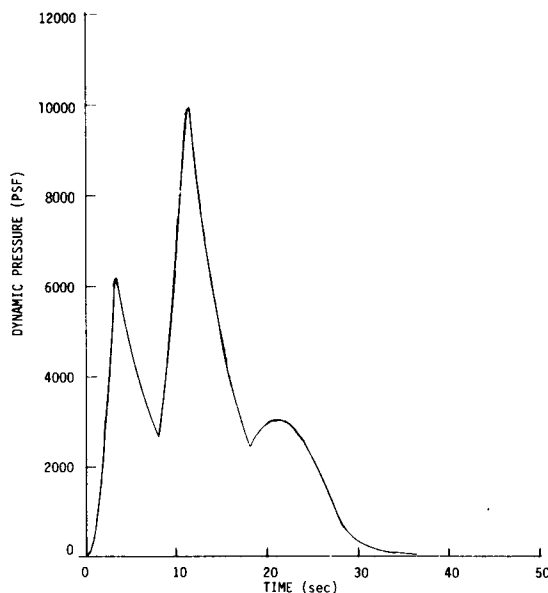


Figure 6 - Dynamic Pressure vs. Flight Time

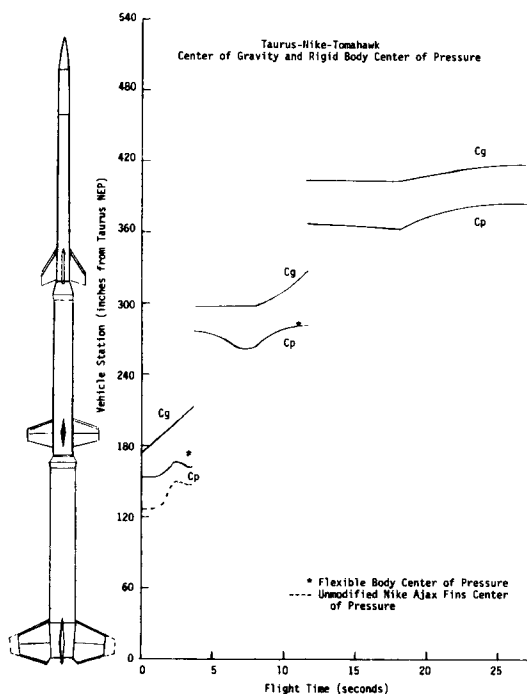


Figure 7 - Taurus-Nike-Tomahawk Stability Characteristics

These fins may be utilized for light-weight payloads. At second stage maximum dynamic pressure, the rigid-body stability margin (based on 16.25 inch Nike diameter) is 2.59 calibers, with a flexible-body stability margin of 2.42 calibers. This is only a 6.5% reduction in stability. The stability index is 0.29, again well below the 0.5 maximum limit.

A full six-degree-of-freedom dynamic stability analysis for the proposed Taurus-Nike-Tomahawk vehicle is not presented here. However, steady-state roll rate calculations were performed and compared with the natural aerodynamic pitching frequency to identify pitch-roll resonance regions. A number of fin cant combinations were evaluated; a feasible combination appears to be as follows:

- Taurus - 5 minutes
- Nike - 40 minutes
- Tomahawk - 15 minutes
- (all clockwise)

Taurus Nike Tomahawk
120 lb. Payload - 83° QE WFC

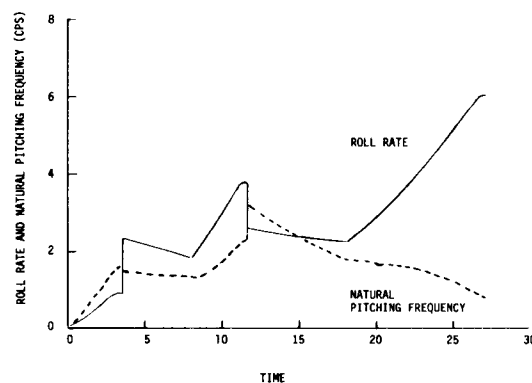


Figure 8 - Steady-State Roll Rate and Natural Frequency vs. Flight Time

The resulting steady-state roll rate profile for the above fin cant combination is plotted in Figure 8. The natural undamped aerodynamic pitching frequency is also plotted for comparison. The only resonance crossing occurs during Tomahawk coasting prior to ignition. Resonance at this point occurs at considerably less dynamic pressure than the similar resonance condition for the two-stage Taurus-Tomahawk. The maximum roll rates for each of the stages occurs at respective motor burnout points:

- Taurus Burnout - 0.9 cps
- Nike Burnout - 3.8 cps
- Tomahawk Burnout - 6.1 cps

Other Potential Three-Stage Vehicles

Consideration of using a Taurus-Nike tandem booster system with the Tomahawk sustainer led to the possibility of using this approach to enhance the performance of other existing two-stage launch vehicles. Any vehicle currently boosted by a Nike would potentially lend itself to Taurus-Nike tandem booster application. In the NASA Sounding Rocket Program, the Nike is used as a booster for Orion, Malemute, and Black Brant V sustainers. Used in conjunction with a Taurus-Nike tandem booster system, these sustainers form the vehicle configurations presented in Figure 9.

These three vehicles are proposed in concept only; no attempts have been made here to establish the feasibility of these flight systems. The Taurus-Nike-Orion and Taurus-Nike-Malemute combinations would be "bolt-together" systems. No new hardware would be required, since both the Orion and Malemute are flown with clamp-together interstages compatible with the Nike. A Nike ignition subsystem would be required, however. For the Black Brant V sustainer, a clamp-together interstage between the Nike and Black Brant V would have to be designed.

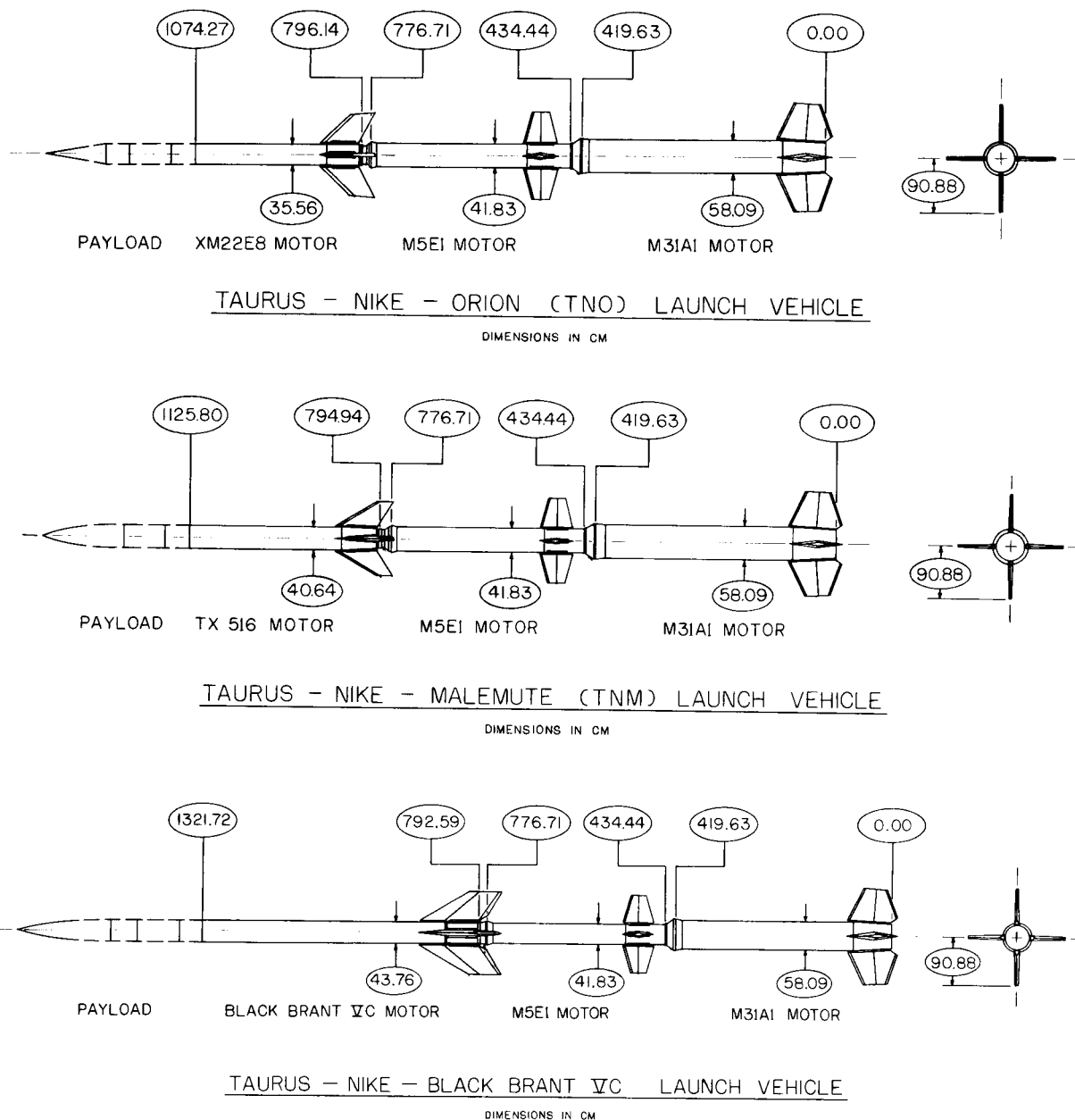


Figure 9 - Orion, Malemute, and Black Brant V Sustainers in Combination with Taurus-Nike Tandem Booster System

Since the Malemute and Black Brant V sustainers are currently being flown with the Terrier MK 12 Mod 1 (X256A1) booster, a tandem booster concept utilizing the Talos MK 11 Mod 2 (X251C1) as a first stage in conjunction with the Terrier as a second stage is proposed for these sustainers. The Talos-Terrier combination has been used successfully by Sandia Laboratories in the Talos-Terrier-Recruit (TATER) vehicle designed for nose-tip and heatshield materials research.³ The proposed three-stage sounding rocket vehicles using the Talos-Terrier booster combination would utilize a drag separation interstage between the boosters; the interstage would be a new design.

The launch configurations for the proposed Talos-Terrier-Malemute and Talos-Terrier-Black Brant V vehicles are shown in Figure 10. As with the Taurus-Nike systems, no attempt is made here to establish feasibility of these two Talos-Terrier vehicle systems. The Talos fins considered here are the same as used on the operational TATER II vehicles; these are four tapered double-wedge fins with zero center line sweepback, 5.7 ft² per panel. The Terrier fins are the same 2.5 ft² capped fins considered for Nike second stage application.

Performance estimates have been made for these five potential new three-stage vehicles by performing 3-D flight simulations. The anticipated performance enhancement from these proposed new vehicles is depicted in Figures 11, 12, and 13.

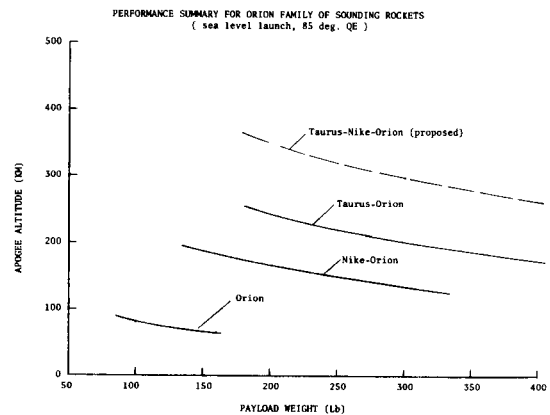
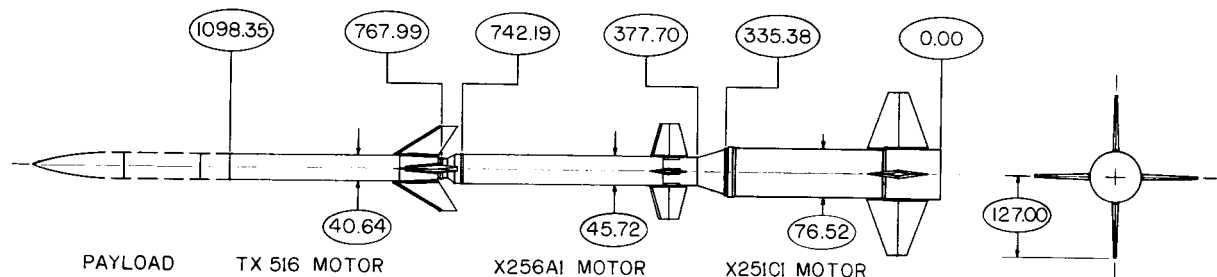
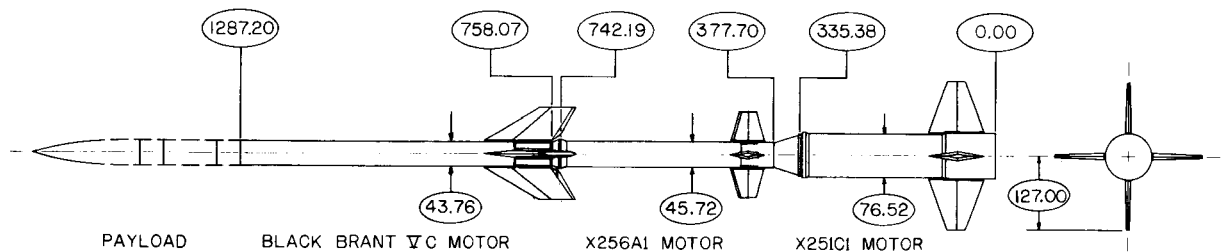


Figure 11 - Performance Summary for Orion Vehicle Family



TALOS - TERRIER - MALEMUTE (TTM) LAUNCH VEHICLE

DIMENSIONS IN CM



TALOS - TERRIER - BLACK BRANT V LAUNCH VEHICLE

DIMENSIONS IN CM

Figure 10 - Malemute and Black Brant V Sustainers in Combination with Talos-Terrier Tandem Booster System

Figure 11 shows a performance summary for the Orion family of sounding rocket vehicles. As seen, the Taurus-Nike-Orion would enhance Orion performance by approximately 100 km over the Taurus-Orion. For the heavier payload weights, the three-stage system would establish a 300 km capability for the Orion vehicle family as compared to the current 200 km capability.

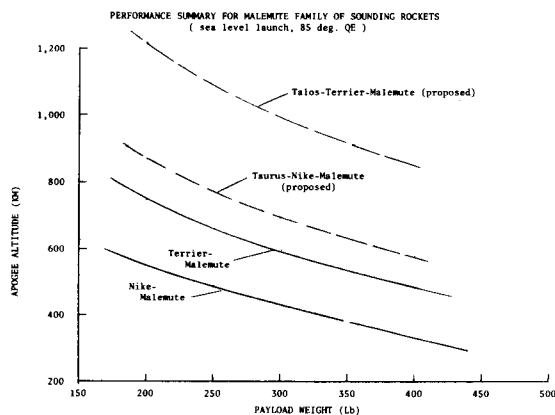


Figure 12 - Performance Summary for Malemute Vehicle Family

A performance summary for the Malemute family of rocket vehicles is presented in Figure 12. The three-stage Taurus-Nike-Malemute has in excess of 100 km more altitude capability than the existing Terrier-Malemute. The proposed Talos-Terrier-Malemute vehicle has over 1,000 km altitude capability for payload weights less than 300 pounds. For payload weights greater than 350 pounds, it has greater performance capability than the currently operational Black Brant X.

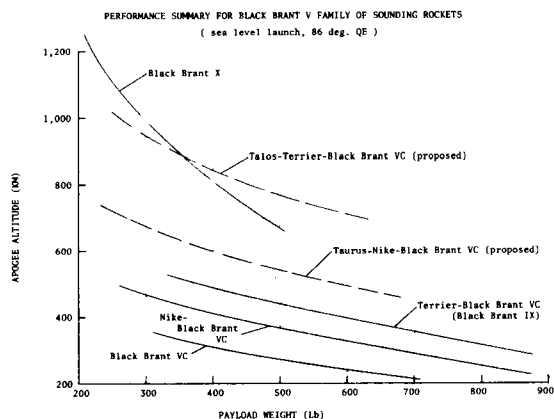


Figure 13 - Performance Summary for Black Brant V Vehicle Family

Similar performance data for the Black-Brant V family of vehicles is included in Figure 13. The Taurus-Nike and Talos-Terrier boosted systems have generally the same performance enhancement over the Terrier - alone boosted system as in the Malemute case. Basically, the Malemute family is more effective for payload weights less than 350 pounds and the Black Brant V family is more effective for payload weights over 350 pounds. This is not the case for the Black Brant X, where the Black Brant V motor is not the final stage. The high mass fraction third stage of the Black Brant X results in a steeper performance curve, with a more severe performance penalty for greater payload weights. It is interesting to note that for payload weights near 350 pounds, the Black Brant X, Talos-Terrier-Black Brant V and Talos-Terrier-Malemute all have approximately similar apogee altitudes at the high launch elevation angles.

Summary

The predicted performance capabilities of six newly-proposed three-stage sounding rocket vehicles using tandem boosters have been investigated. Aeroballistic characteristics have been examined for one of the proposed vehicles--the Taurus-Nike-Tomahawk; based on this brief analysis, this vehicle appears to be a feasible concept. Enhanced performance capabilities of the Tomahawk and Orion sustainers using the Taurus-Nike tandem booster configuration are on the order of 100-200 km; these three-stage vehicles would be a valuable asset in the NASA Plasma Physics rocket program.

Preliminary performance studies have indicated that the Malemute and Black Brant V sustainers, when boosted by a Talos-Terrier tandem booster system, have performance capabilities equal to the Black Brant X for payload weights on the order of 350 pounds. For payload weights greater than 350 pounds, the proposed vehicles have greater performance capabilities than the Black Brant X.

References

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3. Rollstin, L. R., and Fellerhoff, R. D., Aeroballistic and Mechanical Design and Development of the Talos-Terrier-Recruit (TATER) Rocket System with Flight Test Results, Sandia Laboratories Report No. SAND 74-0440, February 1976.