NASA TM-86330

NASA Technical Memorandum 86330

NASA-TM-86330 19850006477

AN OVERVIEW OF SOME MONOPLANAR MISSILE PROGRAMS

M. LEROY SPEARMAN

DECEMBER 1984

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

SUMMARY

A historical review indicates that monoplanar missiles have been in existence since the early 1900's with many concepts and missions evolving from many countries. Many monoplanar systems have been developed and demonstrated in the U.S.; however, few entered the inventory and generally remained for only a short time. By contrast, within the Soviet Union, many monoplanar missiles have also been developed, most of which have remained in the inventory.

A large data bank of monoplanar missile aerodynamics exists and many programs are currently underway. Most monoplanar missile systems have been directed toward use as surface-to-surface or air-to-surface where range requirements may be more important than maneuver requirements. However, the use of monoplanar systems in the surface-to-air and air-to-air roles should not be overlooked.

INTRODUCTION

The knowledge of rocketry and missiles has been in existence for many centuries but the serious thought of using unmanned cruise missiles for possible military application did not begin until early in the 20th century. This thought, of course, was spawned by the advent of successful manned flight with heavier-than-air vehicles. The early missiles generally had an airplane-like appearance since the bulk of available information was related to airplane design. Subsequently, other forms of maneuvering missiles began to appear including those with multiple wings, particularly cruciform, and some even without wings. Among the earliest known cruciform missiles are those attributed to Dr. Max Kramer in Germany during World War II. Kramer developed the Fritz X air-to-surface missile and the X-4 air-to-air missile--both of which were cruciform missiles. Cruciform missiles might be expected to respond rapidly to control commands through the ability to maneuver in any radial plane without the necessity of first rolling and then pitching. Cruciform wings may or may not provide more lift within certain geometric constraints but almost certainly will incur some drag and weight penalty compared to monoplanar or wingless missiles.

Over the past 4 or 5 decades, a large variety of missile missions have been conceived and vehicle concepts that principally include cruciform-, monoplane-, and wingless-types have been developed. In light of some current programs involving monoplanar missiles, it is the purpose of this paper to provide a historical review of monoplanar missile programs with the hope that some insight might be gained into the place and purpose of the monoplanar concept.

SYMBOLS

a.c.	aerodynamic center, percent body length
c.g.	center of gravity, percent body length

C_D	drag coefficient
C_L	lift coefficient
C_N	normal-force coefficient
C_m	pitching-moment coefficient
C_{m_δ}	pitch control parameter
C_{l_δ}	roll control parameter
C_{n_δ}	yaw control parameter
C_{n_β}	directional stability parameter
L/D	lift-to-drag ratio
l	body length
M	Mach number
α	angle of attack, deg.
δ	control deflection, deg.
Λ	leading-edge sweep angle, deg.

DISCUSSION

A historical review of some of the major worldwide airplane-like missile programs (primarily monoplanar) has been compiled in essentially a chronological manner related to the World War I era, the World War II era, and the post World War II era.

World War I Era

A summary of some World War I era programs involving airplane-like missiles is as follows:

FT;AT.- Prior to the outbreak of World War I, British Professor A. M. Low had demonstrated an early form of television and, subsequently, began work (1914-1915) on a project for the British War Office to develop a TV-guided, radio-controlled, pilotless aircraft to combat German Zeppelins as a form of a flying bomb. The device was also to be flown against ground targets with control being provided from a parent aircraft as a true air-to-surface guided weapon. The weapon was concealed under the names F.T. (Flying Target) or A.T. (Aerial Target). Several types were built by Low and his assistants (Poole, Brown, and Whitton), by DeHavilland, by Sopwith, and by the Royal Aircraft Factory. The R.A.F. produced six very graceful monoplanes with radio aerials fitted as chordwise wires on the wings and on the rear of the fuselage. These machines were to be launched from a lorry by means of a compressed air catapult which, in itself, was an idea well ahead of its time. The experiments were successful, but for reasons unknown, no operational use of the weapon was ever made. Low went on to produce radio-controlled rockets in 1917, and these appear to be true ancestors of various similar devices that emerged in World War II and claimed as the invention of others. Flight experiments continued with the radio-controlled monoplanes after the war, and, in 1921, a number of them were flown from the aircraft carrier, H.M.S. Argus. These monoplanes took off under their own power from a trolley undercarriage.

Larynx.- A surface-to-surface monoplanar missile initiated by the British in 1925 with the requirement to carry a 200-pound warhead 200 miles in one hour. The Larynx was launched with a hydraulic catapult and used a gyroscope autopilot for guidance. The Larynx was extensively tested on a desert range in Iraq in the 1928-30 time period and may well have been the world's first guided SSM.

Kettering Bug.- Also during World War I, the Kettering Aerial Torpedo (the "Bug") was developed in the U.S. The Bug was invented by Charles F. Kettering of Dayton and built by the Dayton-Wright Airplane Company in 1918 for the U.S. Army Signal Corps. The unmanned Bug was a propeller-driven biplane with a speed of 120 mph and a range of 75 miles. Takeoff was accomplished under power from a dolly running on a track. Guidance to the target was provided by a system of on-board preset vacuum-pneumatic and electrical controls which, after a predetermined time, would shut off the engine, release the wings, and cause the Bug to plunge to the target where its 180 pounds of explosive detonated on impact. The first tests were made at the Sperry Gyroscope plant using an autopilot-controlled recoverable aircraft. Although the initial testing was successful, World War I ended before the Bug could enter combat. Less than 50 Bugs were completed before the end of the war and the Air Service continued additional tests with these. However, a scarcity of funds in the 1920's halted further development, and the progress of U.S. guided missiles was destined to wait for several more years.

SSW.- A remotely controlled glide bomb suggested in 1914 for the German Navy by Wilhelm von Siemens of Siemens-Schuakert Werk (SSW). Flight tests from aircraft and airships were made of both biplanes and low-silhouette monoplanes with weights from 661 pounds to 2205 pounds. The vehicles were designed to split in half upon command and deliver a torpedo just above the water. All were wire-controlled with a bang-bang rudder that self-centered after each command and elevators which remained in the position last commanded.

Telebombe.- During World War I, the Italian scientist, A. Crocco, worked on a stabilized glide bomb known as Telebombe. These devices were minature biplanes having a span of 26.4 inches. A dozen or more were tested in 1920-22 using a primative autopilot, the gyro and servo-controls being fed from an air bottle. It was claimed that the 44-pound airframe delivered a 176-pound bomb to a distance of 6.2 miles when launched at an altitude of 9,840 feet.

Type 212.- Russia had many pioneers in rocketry and the tradition was maintained by the Soviet Union. N. I. Tikhomirov set up a laboratory in 1921 that became the Gas Dynamics Laboratory (GDL) in 1928. Work here in the 1930's led to a controllable-thrust liquid-propellant engine capable of making up to 50 firings with a total burn-time of 30 minutes. Such an engine was used as a sustainer engine by S. P. Korolev of the Reaction Propulsion Research Institute who, in 1933, headed the design of a winged rocket called Project 212. The vehicle had a low monoplane wing, conventional tails, and conventional controls, and flew twice in 1939 under autopilot control. It was reported that the vehicle, with an airframe weight of 331 pounds and with 66 pounds of fuel, carried a 66-pound warhead for a distance of

31 miles at 311 mph. No guidance system was used with the 212. However, a follow-on system known as Type 212A was started in 1937. Little is known about Type 212A except that it was similar in appearance to its predecessor, was stressed to fly at 621 mph, and probably had a guidance system, all of which potentially could have made Type 212A the most formidable tactical missile of the pre-World War II days.

World War II Era

A summary of some major World War II era monoplanar missiles is as follows:

HS 293.- This was a prolific and diverse program of ASM's developed in Germany by the Henschel missile team under the direction of Herbert A. Wagner. The airplane-like configurations had straight monoplanar wings with symmetrical airfoils and ailerons, a horizontal tail with elevator, a small dorsal and large ventral directional surfaces. In 1940, work was underway on a sea-skimmer version with a dynamic pressure-sensing system used to alter the elevator angle. Among the many versions were missiles for underwater attack as well as steep dive attacks. Guidance and control included wire (up to 19 miles), radio command (with up to 18 channels), and TV. An HS 293 sank the HMS Egret on August 27, 1943 for what may have been the first casualty in the history of air-to-surface guided missiles. A clean design underwater attack version, known as the GT 1200, had rocket motors for air flight and underwater use, and air flight controls as well as underwater controls.

Zitteroschen.- Possibly the first winged supersonic guided missile (M = 1.5) is credited to Dr. Voepl of Henschel in 1944. The missile had triangular monoplanar wings and an inverted T-tail. Roll control was maintained by bang-bang spoilers behind the trailing-edge of the wing.

BV 143.- Blohm and Voss of Germany developed several glide torpedoes in the 1930's that were equipped with end-plated monoplanar wings and tails for sustained glide. The BV 143, developed in 1942, as a glide torpedo had stubby monoplanar wings and tails equipped with ailerons, elevator, and rudder controlled by an autopilot. The sea level approach was to be set by a feeler arm that extended seven feet beneath the body; however, four BV 143's, flown in 1943, all went into the sea prematurely.

BV 246.- The BV 246 was another glide-bomb design by Blohm and Voss (1942-43) with a beautifully streamlined body, a cruciform tail with most of the fin-rudder beneath the body, and a high wing with an amazing aspect ratio of 25.5. Despite a wing-loading of about 102 psf, the BV 246 had a glide ratio of 25 to 1 and demonstrated ranges of up to 130 miles. Various guidance and command links were investigated including radio, infrared, a beam system similar to ILS, and passive radar. The best system appeared to be radar homing. Although over 1100 had been delivered within a two-month time period, the project was cancelled in February 1944 and few of the missiles were used.

V-1.- Perhaps one of the best known, and most used, winged guided cruise missile was the Fieseler Fi 103 (vengeance weapon, V-1) developed in Germany for use in World War II. The original concept stemmed from pulsejet engine research begun by Paul Schmidt in 1928, which became the propulsion system for a flying bomb concept proposed by Robert Lusser of Fieseler Werke in 1941. The V-1 was about 26 feet long with a wing span of a little over 17 feet. A conventional horizontal and vertical tail were used and the pulsejet engine was mounted above the afterbody using a forward pylon (which contained a fuel line) and the vertical tail for support. Elevator and rudder controls were provided, but no ailerons. Guidance was accomplished with a preset compass for heading, an autopilot, an aneroid for altitude, and an air-log propeller which determined range and commanded the terminal dive. At least 29,000 missiles were reported to have been produced. Thousands were surface-launched against England and Belgium and some 1200 modified versions were air-launched from the Heinkel III bomber. With a total launch weight of about 4800 pounds, a warhead of 1870 pounds was delivered over a range of about 150 miles at an altitude of about 2500 feet at a speed of about 400 mph.

Feuerlilie.- A German research project, intended to be a SAM, was tested extensively during 1941-44. The vehicle that evolved had a swept monoplanar wing mounted at the rear of the body with wing-tip vertical tails. Trailing-edge flap controls were used and the vehicle had an autopilot and radio command.

Schmetterling HS 117.- A SAM study begun by Wagner of Henschel in 1941. Visual tracking was required, with control by means of bang-bang spoilers on the wing. The HS-117 had a slightly swept monoplanar wing and cruciform aft tails.

A-9.- Another development at Peenemunde was the A-9, which was a winged version of the ballistic vengeance weapon V-2 (A-4). The purpose of the A-9 was to increase the range of the A-4 by taking advantage of the tremendous kinetic energy available after power cutoff to extend the aerodynamic glide through the use of swept-back monoplane wings. Two A-9's were flight tested during the winter of 1944-45--the first being a failure, and the second being successfully launched and reaching a Mach number of about four. This was probably the first winged guided missile to achieve supersonic flight.

Funryu 4.- Other World War II era missile concepts include the Japanese Funryu 4, a SAM system with fixed tails and a monoplanar wing equipped with elevons for twist and steer control. A simple autopilot was used and radar command guidance with a computer (and probable human assistance) to drive into coincidence the sight-lines of two radars, one tracking the target, and the other tracking the missile.

Miles Hoop-la.- In 1940, recognizing the dangers of bombing German targets, Miles Aircraft in Great Britian proposed a pilotless flying bomb, the Miles Hoop-la. The Hoop-la was a small propeller-driven monoplane built around a 1000-pound bomb. Such a cruise missile would probably have been relatively inexpensive but the British government showed not the slightest interest.

GB Series.- Several ASM projects started in the U.S. in 1940-41 but most suffered from official disinterest. One project that continued was the Guided Bomb (GB), the first of which (GB-1) was a standard 2000-pound bomb fitted with a 12-foot span wing and twin-tail booms to support twin vertical tails and a horizontal tail. At the rear of the bomb was a radio receiver and control servo which biased a simple Hammond autopilot to keep the bomb flying correctly and, in some versions, to impart course corrections. The original GB-1 had no guidance and was merely launched from a relatively safe stand-off distance of 20 miles from an altitude of 15,000 feet. The first use was against Cologne in May 1944 when 109 GB-1's were launched from B-17's with poor accuracy. Subsequently about 1000 were launched at various targets but the accuracy was generally worse than that of a free-fall bomb. Later versions from GB-2 to GB-15 incorporated guidance changes including TV, IR, light-contrast, direct-visual, and the possibility of improved accuracy was indicated principally in test flights.

BG Series.- Both the USAAF and the Navy developed some simple ASM's in the Bomb Glider (BG) category--the intent being to tow the airplane-like vehicles to the vicinity of the target and, upon release, to guide them remotely (radio or other) to impact.

BQ Series.- A series introduced by the Army in 1942 defined as Controllable Bomb, Grounded Launched. Some, such as the XBQ-1 by Fleetwings, were completely new designs to be used as SSM's. Others included converted B-17 and B-24 bombers to be used as ASM's with radio command equipment and autopilot/flight-control servos. With the entire fuselage filled with 20,000 pounds of explosives, the converted B-17's (BQ-7) were to take off with a human crew who set the course, confirmed hand-over of the radio control and then bailed out near the English coast, while the BQ-7 continued under the control of a "mother aircraft." Other guidance schemes including ground control by radar or TV were tried. At least eight BQ-7 missions were flown but with relatively poor success. Two Navy Liberators were also converted (BQ-8) and equipped with TV guidance from an accompanying B-17. Loaded with 25,000 pounds of high explosives, these constituted possibly the largest warhead of conventional explosives ever carried by a single weapon. One of the BQ-8's, though heavily damaged by flak, did place a stupendous explosion on a German airfield on September 3, 1944.

Brakemine.- The British Brakemine originated in 1942 in an attempt to work out a SAM that could ride a radar beam locked-on to a target. The Brakemine had mono-planar wings and aft tails and used radio-command guidance; however, what was becoming a promising program was dropped.

Stooge.- The British reluctance to develop even simple missiles during World War II was further demonstrated with the Stooge. The Stooge, built by Fairey, had an airplane configuration with end-plated monoplane wings and aft tails, and used a simple autopilot to drive the ailerons and elevator and radio-command for steering. The Stooge was to be ship-launched to defeat Kamikaze attacks. On V-J day, the program was completely abandoned although successful flights had been made.

Hs 298.- The first AAM to be built in the world is thought to be the German Hs 298 which started into production just as the war ended. The Hs 298 was a swept-wing monoplane with an aft stabilizer having tip-mounted twin vertical fins. It was equipped for radio control of the ailerons and elevator for twist and steer control (there was no rudder).

Japanese ASM's.- The Japanese attempts to build an ASM during 1942-44 included some airplane-like radio-command guided configurations with relatively high-aspect-ratio monoplane wings and horizontal stabilizers with twin-tip vertical fins. These systems included Funryu 1, I-GO-1-A and I-GO-1-B. All were flight tested and pre-production of the last of the series are reported to have numbered 180 by the end of the war.

Kamikaze.- The Fuji Hikoki MXY7 "Ohka" (Cherry Blossom) was a Japanese suicide weapon used primarily for antishipping during the closing months of World War II. The Ohka carries a 2645-pound warhead for about 55 miles with a glide speed of 229 mph and a maximum dive speed with a rocket motor of 615 mph. The Ohka was a small conventional airplane design with monoplane wings and horizontal stabilizer with twin-tip vertical tails. The Ohka, which was quite effective against U.S. naval forces, used a "man-in-the-loop" human pilot for guidance and control, who, of course, perished at the termination of the mission.

Bat.- The Bat was an Army/Navy minature airplane with a high-swept wing and a low-horizontal tail with twin-tip fins. Used primarily as an antishipping glide weapon, the Bat had a pulsed radar homing system with autopilot servos to drive the stabilizer and wing elevons. Bats successfully sank many Japanese ships including a destroyer sunk from a distance of 20 miles. Some Bats with modified radars successfully homed on bridges in Burma.

Gargoyle.- The first missile by McDonnell, this ASM began in 1943 as a glide bomb but rocket propulsion was added later. The Gargoyle reflected some cruise requirements in that it had a fat, lifting-type body, a low-swept wing, and a butterfly tail. It carried a tracking flare but a guidance system was never defined. A 1000-pound warhead was typically carried for range of about 5 miles at 690 mph. Although flying in 1944, the Gargoyle was reduced to a research program at the end of the war.

Post World War II Era

A summary of monoplanar missile concepts during the post World War II era is as follows:

JB Series.- A series of jet-bomb developments began with the USAAF shortly after the end of the war. In the series was the JB-2 Buzzbomb, an Americanized version of the German V-1 using a Ford pulsejet engine. About 330 were built, some being sled-launched at Holloman, but most being air-launched at Eglin. The JB-1 was a Northrop flying-wing design powered by two small GE turbojets and carrying two 2000-pound bombs in wing root pods. The JB-10 was also a Northrop flying wing with an integral Ford pulsejet which flew 200 miles with a 3203-pound warhead in 1945. The entire JB program was terminated in March 1946.

Gorgon.- A family of U.S. Navy missiles that began development in 1946 for proposed roles of SAM, SSM, ASM, and AAM. The first Gorgons were canard configurations with rear-mounted, shoulder-high monoplane wings, with both turbojet and rocket versions. Later Gorgons, by Martin, had the wings mounted ahead of the tailplane and had an underslung ramjet. The project was terminated in 1953.

Kingfisher.- The Kingfisher, developed in 1948 by McDonnell as a Navy air-launched ASW, had small monoplanar wings, a butterfly tail, and a pulsejet engine. With a 1000-pound warhead, it was intended to home on either ships or submarines.

Loon.- The Loon was a naval version of the USAAF JB-2 which was derived from the German V-1. In 1946, the Navy program began with the missile designation of KUW-1, later the LTV-N-2, from whence came the name Loon. Versions were developed for launching from ships or submarines. For submarine deployment, the Loon was carried in a watertight drum and, after surfacing, the wings and booster rockets were attached and the missile launched from a short, aft-facing ramp. Although many Loons were successfully fired, the system did not become operational and was terminated in 1952.

Snark.- Among the first intercontinental cruise missile programs was the U.S. Snark program begun in January 1946 by Northrop. The SM-62A Snark was a large, pilotless, bomber with a highly-swept wing and no horizontal tail. The launch weight was about 60,000 pounds which included 26,000 pounds of fuel for the J-57 sustainer jet engine, and a nuclear warhead that could be carried up to about 6300 miles at a cruise Mach number of 0.93. Guidance was provided by a star-tracking inertial system with a zero-g dive commanded at the target. After becoming operational with SAC in 1957 and achieving numerous 11-hour full-range flights, the system was deactivated in 1961.

Navaho.- The Navaho, a significant cruise missile program, was begun in 1947. The contractor, North American, produced the SM-64 Navaho, with delta wings and canard and twin ramjet engines. An inertial guidance system was used and the Navaho, which weighed 290,000 pounds at launch flew at a Mach number of 3.25 at over 60,000 feet for a distance of 6325 miles carrying a nuclear warhead. Pivoting wing tips provided roll control, an all-moving vertical tail provided directional control, and the canard surface provided pitch control. Although several successful flights were made and much was learned about ramjet propulsion, canard-configurations, cryogenic propellants, flight-control systems, advanced honeycomb structures, inertial guidance, and many other items of technology, the program was cancelled in July 1957 after being severely lambasted by the media as a waste.

Matador.- A program to develop the TM-61 Matador tactical cruise missile by the Martin Company was approved in February 1951. The Matador had a high swept-back wing and a T-tail. Cruise propulsion was provided by an Allison J-33 centrifugal turbojet with a flush lower surface inlet. The original guidance required line-of-sight radio links and limited the usable range to much less than the design 650 miles. Phase out began in 1959.

Mace.- A follow-on to Matador by the Martin Company that was somewhat similar in configuration. The TM-76 Mace could achieve full range with either of two guidance systems--terrain following or inertial. The system became operational about 1959 and phase out began in the late 1960's.

Bomarc.- Originally designated as the XF-99 pilotless interceptor in 1949 and later redesignated the IM-99 and CIM-10. Developed by Boeing and the University of Michigan Aeronautical Research Center, from which the name Bomarc was extracted. The Bomarc was an airplane-like configuration with a monoplanar delta wing and conventional aft tails, each with tips clipped. The cropped wing tips were arranged to pivot as ailerons for roll control, the top of the vertical fin was deflected for a rudder, and the horizontal tail was all-movable for pitch control. Sustained propulsion was provided by two ramjet engines with a cruise speed of about $M = 3$ at altitudes from 60,000 to 80,000 feet for an intercept range of about 200 miles. Initial guidance was semi-automatic from the ground with final lock-on and terminal homing being provided with an on-board pulse-doppler radar. An advanced version of the Bomarc (more thrust, more fuel, improved homing radar) resulted in almost doubling the intercept range and made possible flight to about $M = 3.95$ at 100,000 feet. It was said that the highly sensitive terminal-homing radar was capable of detecting a target flying at 50 feet from an interceptor altitude of 70,000 feet. Bomarc was fully operational by 1957 and, in training flights, proved to be effective in many types of intercepts against fighter, bomber, and missile target drones. More than 700 models were produced. Production stopped in 1965 and the last operational squadron was deactivated in 1972.

Rigel.- The Navy initiated the Rigel program with Grumman in 1946 to develop a long-range supersonic cruise missile with ramjet propulsion. The design range was 576 miles at $M = 2$ with a 3000-pound warhead. The test vehicles had horizontal canard surfaces and cruciform aft surfaces. Early versions used a nose inlet with integral ramjet and later versions used twin ramjet, mounted on the tips of the horizontal wings. Grumman began testing full-scale versions of this first true supersonic ramjet missile system in 1951 but, despite encouraging results, Rigel was cancelled in 1952.

Regulus I.- A Navy program started in parallel with Rigel in 1947, but far less advanced, involved a minature airplane concept with a nose inlet and turbojet propulsion designed for a range of 400 miles at speeds slower than most fighter airplanes of the day. The Regulus I, developed by Chance Vought, was for submarine launch (while surfaced) and was equipped with a conventional swept wing with elevon controls, no horizontal tail, and a small vertical tail and rudder. An autopilot was used with radio-command signals from submarines. It was the intent that Regulus I be used only against large fixed targets such as cities. Although some submarines were designed and built to accommodate the Regulus, deployment was relatively small and short-lived--from about 1955 to 1964. Some missiles were relegated to the role of target drones (KDU-1).

Regulus II.- The Regulus II submarine-launched cruise missile, also produced by Chance Vought, began in 1953 and was a substantially different vehicle than the Regulus I. The Regulus II had a scoop inlet on the underside of the body that directed air to a J-79 turbojet. The design range was over 1000 miles at a Mach number of about 2. A swept wing with elevons was used, a vertical tail with rudder, and a small fixed canard was added as a destabilizer, and an inertial guidance system was used with radar terminal homing. The system, although successfully demonstrated, never became operational, and over a hundred Regulus II vehicles were used as target drones (KD2U). Abandoning the Regulus II missile in 1959 brought to a halt the Navy programs for a cruise missile for about the next 15 years when, in 1974, the Tomahawk program began.

Corvus.- Corvus, a Navy supersonic ASM begun in 1959 by Temco, was a winged rocket vehicle designed to home on radars from a distance of about 50 miles. After achieving fully guided flights, the program was cancelled in 1960.

Crossbow/Longbow.- Crossbow, developed by Radioplane, was a long-range cruise missile with a low monoplane wing, horizontal tail with twin-tip fins, and an underslung inlet feeding a small turbojet engine. Cruise speed was about 575 mph. A multi-band passive seeker was used to home on radar. Crossbow was terminated and replaced by the longer-range (200 miles) Longbow which, in turn, was cancelled in early 1960.

Rascal.- An unusual ASM supersonic strategic penetrator developed by Bell for carriage on the B-47. The Rascal, though a cruciform configuration, was controlled by upper and lower nose rudders, a fixed horizontal wing with ailerons, and folding upper and lower rear fins. Range was intended to be about 75 miles, using inertial guidance, at a speed of M = 1.6. Flights began in 1953, and a brief operational period existed from 1957 to 1959, prior to Hound Dog.

Hound Dog.- Program development started in 1957 to provide SAC with a long-range strategic penetrating ASM. The configuration was derived by North American from the earlier Navaho program. Hound Dog had a canard pitch control, rear delta wings with ailerons, a vertical tail with rudder, and was powered by an underslung J-52 turbojet. The engine was non-afterburning with variable inlet and nozzle to match flight conditions from tree-top level up to 55,000 feet at speeds up to M = 2. The Hound Dog engines were used to add thrust to the B-52 for takeoff and the missile fuel was topped-off in flight before launch. The missile range was about 700 miles using an inertial guidance system that was updated prior to launch by the aircraft navigation system and an astro tracker in the launch pylon. Terminal homing was by radar and by tercom. Hound Dog became operational in 1961 and was withdrawn in 1976, prior to the ALCM program.

Quail.- The Quail, by McDonnell, which first flew in 1958, was a high-wing tailless monoplane with twin vertical fins. Although given a missile designation (GAM-72), the Quail was an ECM vehicle, which, when folded, could be carried internally by B-52's. The Quail was powered by a J-85 turbojet, and with a range of about 250 miles, was intended to perform deceptive maneuvers to confuse enemy defenses. About 492 were in the SAC inventory in 1962 but all were phased out by the late 1970's. Plans to replace the Quail with newer systems, such as SCAD, have failed in the funding process.

Bloodhound.- The British Bloodhound SAM work began in 1949. Bloodhound has pivoting monoplane wings near mid-body, fixed aft horizontal tails, and two ramjet sustained engines above and below the rear of the body. Control is provided by a true twist-and-steer method. A semi-active homing radar drives the wing panels differentially to reach the proper roll plane and then in unison to provide the maneuvering force. The missile flys at about M = 2 for a range of over 100 miles.

Blue Steel.- Blue Steel was a large British ASM begun in 1954 for launching from Vulcan and Victor bombers. The 15,000-pound missile was designed for M = 2 flight for a range of up to 200 miles, depending on launch altitude, with maximum altitude being about 80,000 feet. The missile had small delta canards for pitch control, a delta wing with ailerons and slightly turned-down tips, and folding dorsal and ventral tail fins for semi-submerged carriage. Control was by twist and steer; guidance was inertial with linkage to the airplane navigation system for periodic updating. The missile was operational by 1962 and progressively was removed from the inventory during 1973-75 and the program was abandoned.

Arsenal 5501.- A French cruise missile development based upon the German V-1. The 5501, however, had an autopilot and radio-command guidance. Flight testing began with ground launches in 1948 and air-launching in 1949. The 5501 was terminated as a missile in 1951 and relegated, for a while, to the role of a target drone--eventually becoming the Nord CT-10.

SE. 4200.- A French developed cruise missile developed by SNCASE, first flown in 1955. The SE. 4200 Caisseur (Smasher), one of the first cruise missiles to be built, had an integral ramjet body, delta monoplane wings with elevons and tip-mounted vertical surfaces with rudders. The weak feature was guidance by radio command and visual tracking with bright flares. A later version, the SE. 4400 used radar tracking but still had line-of-sight limitations and poor accuracy. The theoretical range of about 129 miles was limited, in reality to about 10 miles. Service was terminated in the early 1960's.

RB 04.- A Swedish air-launched anti-shipping missile having aft-mounted wings with twin tip fins and cruciform canard surfaces. The missile has a range of about 12 miles and follows a sea-skimming trajectory using a programmed autopilot, a radar altimeter, and active radar terminal homing.

RB 08A.- Starting in 1959, the RB 08A was developed by Sweden from the French Nord CT-20 target drone to function as an anti-ship cruise missile. The missile has a swept monoplane wing, a vee tail, and ailerons and elevator controls. Sustained propulsion is with a turbojet engine of 880 pounds thrust. A warhead of 550 pounds is carried for over 110 miles. Guidance is provided by launch azimuth, a precision autopilot, a pre-set altitude lock, and, near the target, active radar homing is used to detect the target and provide terminal control. Land-based and ship-board installations are both used.

R.511.- The Matra R.511, appearing in 1956, was a twist-and-steer AAM having an aft delta wing with ailerons, canard pitch controls, twin vertical wing-tip fins, and a centerline ventral rudder. Guidance was by semi-active radar for a range of about 4.3 miles. The missile was still in service at least through the late 1970's. In later designs, such as the R.530 and R.550, Matra reverted to cruciform designs.

Sispre C-7.- The first Italian missile was an AAM with fixed cruciform tails and a pivoting monoplanar wing. The wings operated differentially for roll and in unison for pitch to provide twist-and-steer control. The missile used an infrared seeker and reached the flight test stage in 1957. A small production series was made in 1961-62.

Ikara.- An Australian developed ASW that is basically a torpedo mounted to a fuselage to which aft delta wings and tail fins are added. The missile is launched in the general direction of the target and uses an autopilot, a radio altimeter, and steering by radio command to the wing elevons.

Malafon.- A French developed ASW that consists of a torpedo attached to a glider-type container having pivoting wings and an aft horizontal tail with twin tip fins. The Malafon is tracked optically and is steered by radio command to the variable incidence wings.

Soviet Monoplanar Systems

The U.S.S.R. has been particularly prolific with the use of airplane-like missile concepts since World War II, particularly for use as ASM's and SSM's. A summary of the major Soviet programs is as follows:

AS-1 Kennel.- Swept wing, conventional tail, turbojet powered with a nose inlet. Carries a 2000-pound warhead for about 50 to 90 miles at M = 0.9. Cruises as a radar beam rider with terminal homing by active or semi-active radar.

AS-2 Kipper.- Swept wing, conventional tail, underslung turbojet engine. Carries a 2200-pound warhead for about 130 miles at M = 1.4. Cruises with programmed autopilot with command override and active radar or IR homing.

AS-3 Kangaroo.- Conventional swept wing and tails with turbojet engine and nose inlet. Carries a 5000-pound warhead for about 400 miles at M = 2. Uses programmed autopilot with beam riding or radio command.

AS-4 Kitchen.- Highly swept delta wings and cruciform tails with probably a liquid fuel rocket engine. Carries a 2200-pound warhead from about 200 to 400 miles at M of about 3.5. Guidance is by preprogrammed inertial autopilot and possibly IR homing.

AS-5 Kelt.- Conventional swept wing and tails with a liquid rocket engine. Carries a 2200-pound warhead for up to 200 miles at M = 0.95. Midcourse guidance is a radio-command preprogrammed autopilot with terminal homing by either active radar or passive radiation. Successfully demonstrated in middle East action.

AS-6 Kingfish.- Highly swept delta wings and cruciform tails, similar to the AS-4 but smaller and lighter. Powered by a liquid or a solid rocket or perhaps a combined cycle type. Carries a 2200-pound warhead for ranges up to 400 miles cruising at about 60,000 feet and M = 3. The performance and accuracy reflects an advanced inertial midcourse guidance with terminal homing by active radar, area correlation, or passive radiation.

SS-N-1 Scrubber.- The earliest of Soviet Navy anti-ship cruise missiles with development starting in the early 1950's and deployment by 1958. The Scrubber had an unswept monoplane wing, a butterfly tail, and a turbojet engine with an underslung inlet. The Scrubber carried either a 1000- or a 2000-pound warhead for about 30 miles (unassisted) or about 130 miles (with a forward observer) at a cruise Mach number of 0.9. The guidance was a programmed autopilot with radio command and active radar homing.

SS-N-2 Styx.- The Styx is a relatively small airplane-like configuration that appeared on small combatants in the Soviet Navy around 1959. The Styx has trapezoidal wing and tail surfaces and is powered with a solid propellant rocket. Styx carries an 1100-pound warhead about 26 miles at M = 0.3. Midcourse guidance is by programmed autopilot with radio command and terminal homing by active radar or IR. Successfully demonstrated by sinking the Israeli destroyer Eilat in October 1967.

SS-N-3 Shaddock.- The Shaddock, the largest of the Soviet Navy cruise missiles, appeared about 1960 and is an airplane-like configuration thought to have relatively stubby wings and aft tails. It is powered by either a turbojet or a ramjet engine. A 2200-pound warhead is carried about 200 to 400 miles at about M = 1.4. Guidance may be inertial, or programmed autopilot with radar altimeter and radio command. Terminal homing could be active radar or IR.

SS-N-7.- Little is known about the geometry but the SS-N-7 is estimated to carry an 1100-pound warhead for a range of 35 miles from a submerged launch using a turbojet sustainer engine. Guidance is probably a programmed autopilot with active radar homing.

SS-N-9.- The SS-N-9 can be surface launched or submerged launched and carries an 1100-pound warhead about 60 miles. Midcourse guidance is inertial with active radar or IR homing.

SS-N-12 Sandbox.- A follow-on version to the SS-N-3 Shaddock probably with an increase in speed to about M = 2.5 and with a range of 300 miles. On the Kiev VTOL carrier installation, the SS-N-12 can be assisted in midcourse guidance by helicopter or by satellite.

SS-N-14 Silex.- Now deployed on several Soviet ships, Silex is thought to be a winged drone carrying an ASW acoustical homing torpedo (similar to Ikara). Cruise range is about 30 miles at M = 0.95 using an autopilot with command override.

SS-N-19.- Apparently an improved SS-N-12 including a submerged launch capability for the Oscar submarines. Also carried on the Kirov cruisers. Midcourse guidance over the 300-mile range may come from helicopters or from satellites.

SS-N-21.- A tube-launched weapon, probably for submarines, thought to be similar in concept to the U.S. Tomahawk. Range is estimated at 900-1200 miles at M = 0.7.

SS-N-22.- Estimated to be a M = 2.5 successor to the SS-N-9. Deployed on Sovremennyy destroyers, Tarantul II corvettes, and reportedly, on a new Navy WIG. Range is probably about 120 miles with midcourse guidance aided by helicopters. Also reportedly flies at sea skimming altitudes for 55-68 miles.

The extent to which the U.S.S.R. has produced monoplanar cruise ASM's and SSM's is impressive. There has been no known use of the monoplane configuration in the AAM category as yet but the future development of highly maneuverable monoplanar AAM's should not be discounted.

An important point to note regarding the Soviet cruise missile family is the rather dramatic growth rate of new systems. It might also be noted that few systems have been deactivated or cancelled but most systems have remained in the ever-growing inventory.

SOME RESEARCH STUDIES

A considerable amount of research effort has gone into the study of missile configurations of various types. A few examples will be used to illustrate some component effects as well as the characteristics of some specific complete configuration concepts.

Component Effects.- Since drag reduction is a benefit that is anticipated for monoplanar missiles, the lift-to-drag ratios are presented in figure 1 for a simplified wing-body model at M = 4 (unpublished). A simple body of revolution was used, to which was attached some delta wing panels of two sweep angles in both a monoplane and a cruciform arrangement. These results indicate approximately a 15-percent increase in the maximum values of lift-drag ratio when monoplanar wings are used--a significant improvement if translatable into range. It might be noted that the monoplane configuration with $\Lambda = 85.2°$ provided essentially the same level of maximum lift-to-drag as the cruciform wings with 78.3° of sweep--a point that could be important if span constraints are a factor.

Some effects of wing panel interference on the generation of normal force are illustrated in figure 2 for a 73-degree delta-wing-body model at M = 2 (unpublished). These results indicate that a single pair of horizontal monoplanar wing panels provide almost the same amount of normal force as four cruciform panels in 45-degree planes. When the upper and lower pair of wing panels in the 45-degree plane are looked at separately, it is seen that the lower pair of panels are reasonably effective in producing normal force and the upper pair of panels are considerably less effective. In addition, when the increments of normal force provided by the upper and lower panels are combined and compared to the complete cruciform arrangement, a small decrement in normal force appears that is indicative of a mutual interference effect between the wing panels.

Specific Complete Configurations.- A comparison of a monoplanar and a cruciform configuration is shown in figure 3. For this investigation, the monoplane (ref. 1) was obtained simply by removing one set of wing panels from a cruciform missile model (ref. 2). The monoplane was tested with a horizontal tail (two panels) control and also with the cruciform tail control (four panels). Some of the results for M = 2.4 and with the controls deflected minus 20 degrees to provide pitch are shown in figure 3 for various arrangements. When pitching in the plane normal to the wings (surfaces horizontal and vertical for the cruciform model), the monoplane offers some advantage in lower drag, higher lift-curve slope, and more effective pitch control. The cruciform missile in the X-position (four controls defected) results in an additional increase in drag and some loss in lift but does, of course, produce a substantial increase in pitch control.

When the cruciform tail is added to the monoplanar missile, an increment in drag and decrement in lift also occurs due to the deflection of four panels, and the pitch control is about the same as that for the cruciform missile. Some observations based on these data are that the monoplanar missile would be a better choice insofar as cruise missions are concerned, and also for high maneuvering capability in a plane normal to the wing panels (which, of course, involves banking for the monoplanar missile). The use of cruciform tails (four control panels), while causing an increment in drag and a decrement in lift, should result in the monoplanar missile having a maneuver capability at least as good, if not better, than the cruciform missile.

The longitudinal/directional characteristics of a monoplanar missile with a cranked wing, cruciform tails, and an elliptic body are shown in figure 4 for $M = 2.86$ (see ref. 3). While this particular arrangement indicated excellent pitching capability to beyond $\alpha = 28°$, a limitation is imposed by the lack of directional stability. This condition, which could be improved upon by such things as a forward movement of the c.g. or an increase in the size of the tails, points out the necessity for concurrently assessing the longitudinal- and the lateral-directional stability.

The longitudinal/directional characteristics of a monoplanar missile with a delta wing and cruciform tails, either in 45-degree planes (conventional) or in 30-degree planes (low profile), are presented in figure 5 (see ref. 4). The low profile tails provide slightly higher values of pitch control effectiveness and slightly higher values of maximum lift-to-drag ratio above $M = 2$. However, for this particular configuration, the low profile tails resulted in lower levels of directional stability.

The longitudinal/directional characteristics of a monoplanar missile with a swept wing, cruciform low profile tails (30° planes), and either a circular or an elliptical body with equal volumes are shown in figure 6 for $M = 2.50$ (see ref. 5). These design arrangements indicate some potential advantages for the elliptic body in the form of a lower longitudinal stability level and a higher directional stability level.

The characteristics of a subsonic cruise missile shown in figure 7 have been extracted from some unpublished results. The configuration has a small monoplanar trapezoidal wing and trapezoidal tri-tail surfaces with conventional control surfaces. The results indicate a nearly constant drag level up to $M = 0.9$, a constant a.c. location at about 45 percent of the body length, and maximum values of lift-to-drag ratio of a little over 7. Directional stability was maintained over the Mach number range, as was the pitch, yaw, and roll control effectiveness. In general, the configuration appears to be reasonably well suited for subsonic cruise missile application.

The characteristics of a supersonic cruise missile illustrated in figure 8 have been extracted from some unpublished results. The configuration has a highly swept monoplanar delta wing and a tri-tail with clipped tips. The maximum value of lift-to-drag ratio is about 4.5 over the supersonic speed range. The lower curves indicate that the center of gravity required for trim at maximum L/D with zero control deflection is slightly forward of the aerodynamic center. Thus, it would potentially be possible to cruise at supersonic speeds at maximum L/D with no trim drag.

The characteristics of a hypersonic cruise missile at M = 5.2 (unpublished results) are shown in figure 9. The configuration has cruciform delta tails in the horizontal and vertical planes and a monoplanar delta wing that was tested in both a high and a low position. Because of interference flow fields related to the wing location, the high wing arrangement provided a more linear and stable pitching moment variation, higher lift-to-drag ratios, and substantially better directional stability characteristics.

Other Concepts.- A brief review of some other candidate monoplanar missile concepts is presented in figures 10 to 12. The configuration in figure 10 is a flat-top, high wing-body with a highly swept arrow-type wing that has negative dihedral near the wing tips. The configuration in figure 11(a) is an all-wing design with a highly swept clipped-tip delta planform that develops into an octagonal cross-section at the base. The concept in figure 11(b) is a highly swept delta wing-body with deflectable tip cones for stability and control. Some experimental data for the concepts shown in figures 10 and 11 may be found in references 6 and 7 for Mach numbers from 1.41 to 4.63. The configuration in figure 12(a) is representative of a high-wing monoplanar concept developed during studies of high speed research airplanes (ref. 9). Such studies are applicable to missiles as well as airplanes and serve a useful purpose in stimulating thought on advanced structures, propulsion systems, thermal protection, flight controls, and numerous subsystems. The configuration shown in figure 12(b) illustrates the use of such technology in a hypersonic, airbreathing, cruise missile concept. Results of some studies of hypersonic airbreathing missiles may be found in references 9 to 12.

MISCELLANEA

While the section heading "Miscellanea" is in no way intended to be facetious with regard to miscellaneous missiles, it is the purpose of this section to briefly review some of the existing experimental data for various monoplanar missile concepts. It is recognized that many sources of applicable data will be excluded from this brief review; however, the intent is to at least partially indicate the extent of the data that is available.

Force and pressure measurements for the Navaho missile will be found in references 13 and 14. Test data for the Regulus II missile will be found in references 15 and 16. Data for the Corvus missile will be found in reference 17. Some target drones are quite representative of monoplanar missiles, such as the Redhead Roadrunner (ref. 18), the AQM-37 Sandpiper (refs. 19 to 22), the Radioplane XQ4-B (ref. 23), the Nord CT-41 (ref. 24), and a research configuration (ref. 25). Some data for various basic research monoplanar canard configurations are contained in references 26 to 36. These research configurations include delta and trapezoidal planforms, single- and twin-vertical tails, and various geometric variations in wing, tail, and canard location. Some results for an airplane-like monoplanar missile with a swept wing and conventional aft tail are found in reference 37. Other monoplanar drone systems have been flown in recent times, such as the High Altitude Supersonic Target (HAST) derivative of the Sandpiper which has achieved M = 4, and the subsonic NV-144 and Beech 997A now in flight test.

EPILOGUE

The nature of this paper is such that definite conclusions or recommendations are not possible. However, a review of monoplanar missile programs--past, present, and future--leads to some observations:

O The history of monoplanar missiles is long and extensive, dating at least to the early years of the 1900's.

O Many vehicle concepts and missions have evolved from many countries.

O Within the U.S., many monoplanar missile systems have been developed and excellent capability has been demonstrated. However, few systems entered the inventory, and those that did remained for a relatively short time.

O In contrast, within the Soviet Union, many monoplanar missile systems have also been developed, most of which are still in the active inventory with a steady influx of new systems continuing to add a growing capability.

O There is a large existing data bank for monoplanar missile development and new technology programs are underway.

O Most monoplanar missiles have been directed toward missions where range requirements are more stringent than maneuver requirements (ASM, SSM) but the possibility of highly maneuverable monoplanes cannot be discounted.

BIBLIOGRAPHY

Rockets and Missiles, Bill Gunston, Cresent Books, New York, 1979.

The International Encyclopedia of Aviation, David Mondey, Crown Publishers, Inc., New York, 1977.

Soviet Air/Land Military Power, Louis J. Arold, Jr. and William F. Hill, Airlandco, La Puente, CA, 1976.

The World's Missile Systems, Seventh Edition, General Dynamics, Pomona, CA, 1982.

World Military Aviation, Nikolaus Krivinyi, Arco Publishing Company, Inc., New York, 1977.

U.S. Fighters, Lloyd S. Jones, Aero Publishers, Inc., Fallbrook, CA, 1975.

Aviation Week and Space Technology, McGraw Hill, Inc., New York, published weekly.

Combat Fleets of the World 1984/85, Jean Labayle Couhat, Naval Institute Press, Annapolis, MD, 1984.

REFERENCES

1. Jernell, Lloyd S.: Stability and Control Characteristics of a Monoplane Missile with Large Delta Wings and Various Tail Controls at Mach 1.90 to 2.86. NASA TM X-71984, 1974.

2. Jernell, Lloyd S.; Monta, William J.; and Flechner, Stuart G.: Stability and Control Characteristics of a Cruciform Missile with Large Delta Wings and Aft Tail Controls at Mach Numbers from 0.60 to 4.63. NASA TM X-3037, 1974.

3. Sawyer, Wallace C.; and Sangiorgio, Giuliana: Stability and Control Characteristics of a Monoplanar Elliptic Missile Model at Mach Numbers from 1.60 to 2.86. NASA TP-1352, 1979.

4. Blair, A. B., Jr.: Stability and Control Characteristics of a Monoplanar Missile Configuration with Two Low-Profile Tail Arrangements at Mach Numbers from 1.70 to 2.86. NASA TM X-3533, 1977.

5. Graves, Ernald B.; and Fournier, Roger H.: Effect of Nose Bluntness and Afterbody Shape on Aerodynamic Characteristics of a Monoplanar Missile Concept with Bodies of Circular and Elliptical Cross Sections at a Mach Number of 2.50. NASA TM-80055, 1979.

6. Foster, Gerald V.: Static Stability Characteristics of a Series of Hypersonic Boost-Glide Configurations at Mach Numbers of 1.41 and 2.01. NASA TM X-167, 1959.

7. Graves, Ernald B.; and Carmel, Melvin M.: Aerodynamic Characteristics of Several Hypersonic Boost-Glide-Type Configurations at Mach Numbers from 2.30 to 4.63. NASA TM X-1601, 1968.

8. Jackson, L. Robert; Kirkham, F. S.; and Weidner, J. P.: Structural Concepts and Experimental Considerations for a Versatile High-Speed Research Airplane. NASA TM 78743, 1978.

9. Hunt, J. L.; Lawing, P. L.; and Cubbage, J. M.: Conceptual Study of Hypersonic Airbreathing Missiles. AIAA Paper No. 78-66, 1978.

10. Hunt, J. L.; Lawing, P. L.; and Marcum, D. C.: Research Needs of a Hypersonic, Airbreathing Lifting Missile Concept. Journal of Aircraft, vol. 16, October 1979, pp. 666-673.

11. Dillon, J. L.; Marcum, D. C.; Johnston, P. J.; and Hunt, J. L.: Aerodynamic and Inlet Characteristics of Several Hypersonic Airbreathing Missile Concepts. Journal of Aircraft, vol. 18, April 1981, pp. 231-237.

12. Hunt, J. L.; Johnston, P. J.; Cubbage, J. M.; Dillon, J. L.; Richie, C. B.; and Marcum, D. C., Jr.: Hypersonic Airbreathing Missile Concepts Under Study at Langley. AIAA Paper No. 82-0316, 1982.

13. Church, James D.; and Taylor, Nancy L.: An Investigation of a 0.05-Scale Model of the XSM-64A Navaho Missile and Booster at Supersonic Mach Numbers, Part I - Force Study. NASA TM X-16, 1959.

14. Church, James D.; and Taylor, Nancy L.: An Investigation of a 0.05-Scale Model of the XSM-64A Navaho Missile and Booster at Supersonic Mach Numbers, Part II - Pressure Study. NASA TM X-17, 1959.

15. Robinson, Ross B.; Driver, Cornelius; and Spearman, M. Leroy: Static Longitudinal and Lateral Stability and Control Characteristics of an 0.065-Scale Model of the Chance Vought Regulus II Missile at Mach Numbers of 1.41, 1.61, and 2.01. NACA RM SL55E31, 1955.

16. Robinson, Ross B.; and Driver, Cornelius: Effects of Various Modifications on the Static Longitudinal Stability and Control Characteristics of a 0.065-Scale Model of the Chance Vought Regulus II Missile at a Mach Number of 2.01. NACA RM SL55I15, 1955.

17. Presnell, John G., Jr.: Investigation of Control Effectiveness and Stability Characteristics of a Model of a Low-Wing Missile with Interdigitated Tail Surfaces at Mach Numbers of 2.29, 2.97, and 3.51. NACA RM L58C19, 1958.

18. Corlett, William A.: Aerodynamic Characteristics of a 0.187-Scale Model of a Target Missile at Mach 1.80 to 2.16. NASA TM X-1304, 1966.

19. Blair, A. B., Jr.; and Fournier, Roger H.: Aerodynamic Characteristics of a Target Drone Vehicle at Mach Numbers From 1.57 to 2.10. NASA TM SX-1531, 1968.

20. Blair, A. B., Jr.; and Babb, C. Donald: Aerodynamic Characteristics of a Revised Target Drone Vehicle at Mach Numbers From 1.60 to 2.86. NASA TM SX-1532, 1968.

21. Blair, A. B., Jr.; and Tudor, Dorothy H.: Effects of Additional Revisions on the Aerodynamic Characteristics of a Target Drone Vehicle at Mach Numbers From 1.70 to 4.63. NASA TM SX-1961, 1970.

22. Blair, A. B., Jr.: Aerodynamic Characteristics at Mach Numbers from 1.60 to 2.86 of a Target-Drone Vehicle with an Underslung Engine Nacelle. NASA TM SX-2299, 1971.

23. Blair, A. B., Jr.; and Carmel, Melvin M.: Stability and Control Characteristics at Mach 1.57 to 2.16 of a Target Drone Model with an Underslung Inlet. NASA TM X-1538, 1968.

24. Spearman, M. Leroy: Longitudinal and Lateral Stability and Control Characteristics of a 1/9-Scale Model of a Twin-Ramjet Canard Target Drone at Mach Numbers from 0.60 to 2.80. NASA TM SX-732, 1962.

25. Spearman, M. Leroy; and Robinson, Ross B.: Wind-Tunnel Investigation of a Ram-Jet Canard Missile Model Having a Wing and Canard Surfaces of Delta Plan Form with 70° Swept Leading Edges. Longitudinal and Lateral Stability and Control Characteristics at a Mach Number of 1.60. NACA RM L52E15, 1952.

26. Boyd, John W.; and Peterson, Victor L.: Static Stability and Control of Canard Configurations at Mach Numbers From 0.70 to 2.22 - Longitudinal Characteristics of a Triangular Wing and Canard. NACA RM A57J15, 1958.

27. Peterson, Victor L.; and Menees, Gene P.: Static Stability and Control of Canard Configurations at Mach Numbers From 0.70 to 2.22 - Lateral-Directional Characteristics of a Triangular Wing and Canard. NACA RM A57L18, 1958.

28. Peterson, Victor L.; and Menees, Gene P.: Aerodynamic Loads at Mach Numbers From 0.70 to 2.22 on an Airplane Model Having a Wing and Canard of Triangular Plan Form and Either Single or Twin Vertical Tails. NASA TN D-690, 1961.

29. Driver, Cornelius: Effects of Wing Height on the Stability and Control Characteristics at a Mach Number of 2.01 of a Canard Airplane Configuration with a 70° Delta Wing. NASA TM X-328, 1960.

30. Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L56L19, 1957.

31. Spearman, M. Leroy; and Driver, Cornelius: Effect of Canard Surface Size on Stability and Control Characteristics of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NACA RM L57L17a, 1958.

32. Spearman, M. Leroy; and Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics at Mach Number 2.01 of a 60° Delta-Wing Airplane Configuration Equipped With a Canard Control and With Wing Trailing-Edge Flap Controls. NACA RM L58A20, 1958.

33. Spearman, M. Leroy; and Driver, Cornelius: Effects of Forebody Length on the Stability and Control Characteristics at a Mach Number of 2.01 of a Canard Airplane Configuration With a Trapezoidal Aspect-Ratio-3 Wing. NASA MEMO 10-14-58L, 1958.

34. Driver, Cornelius: Longitudinal and Lateral Stability and Control Characteristics of Various Combinations of the Component Parts of Two Canard Airplane Configurations at Mach Numbers of 1.41 and 2.01. NASA MEMO 10-1-58L, 1958.

35. Foster, Gerald V.: Effects of Wing Vertical Location on the Stability and Control Characteristics at a Mach Number of 2.01 of a Canard Airplane Configuration With a Trapezoidal Aspect-Ratio-3 Wing. NASA TM X-44, 1959.

36. Spearman, M. Leroy; and Driver, Cornelius: Effects of Forebody Length on the Stability and Control Characteristics at a Mach Number of 2.01 of a Canard Airplane Configuration With a Trapezoidal Aspect-Ratio-3 Wing. NASA TN D-1263, 1962.

37. Spearman, M. Leroy; and Collins, Ida K.: Aerodynamic Characteristics of a Swept-Wing Cruise Missile at Mach Numbers From 0.50 to 2.86. NASA TN D-7069, 1972.

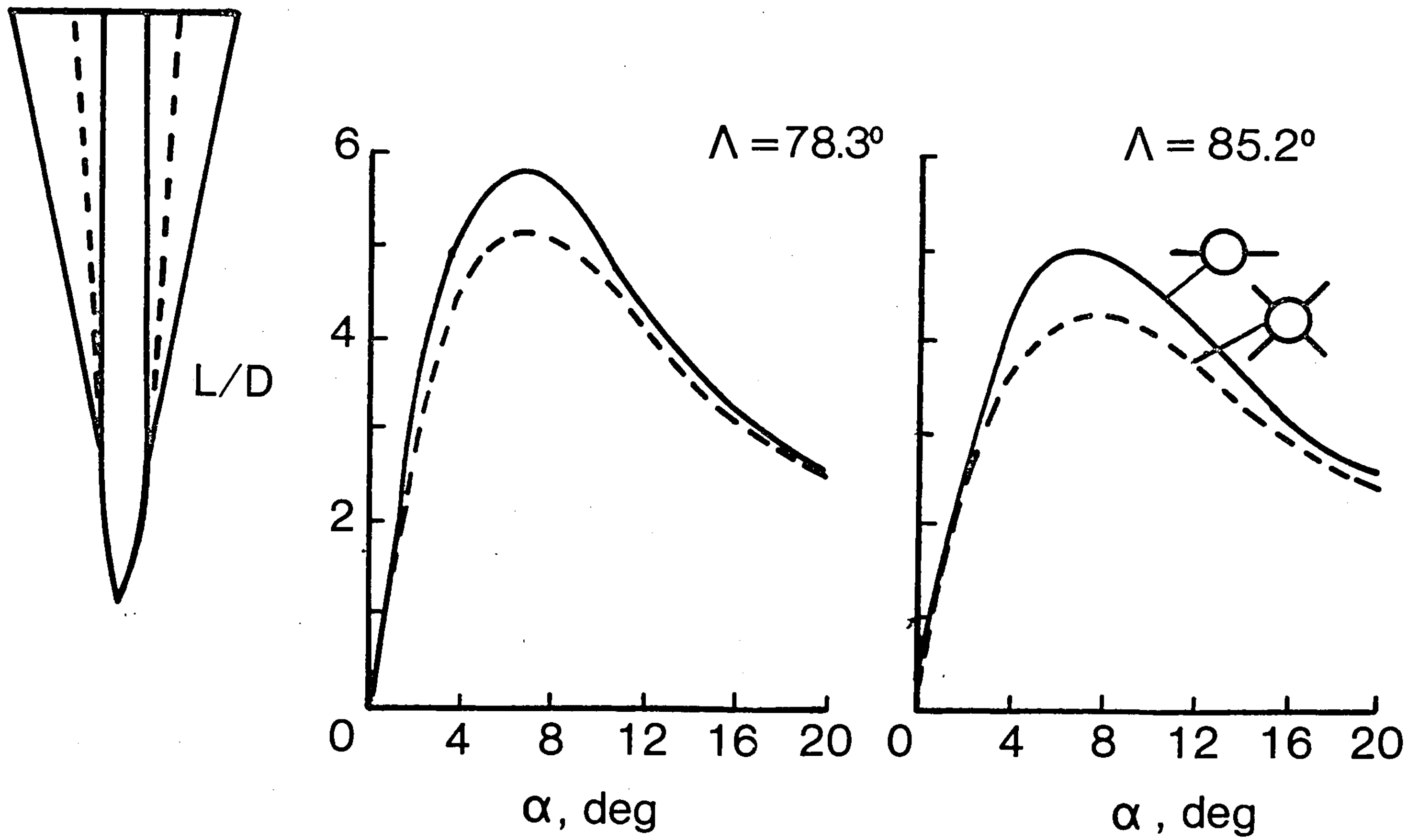


Figure 1.- Lift-to-drag ratios for a monoplanar and a cruciform delta-wing-body concept at M = 4.

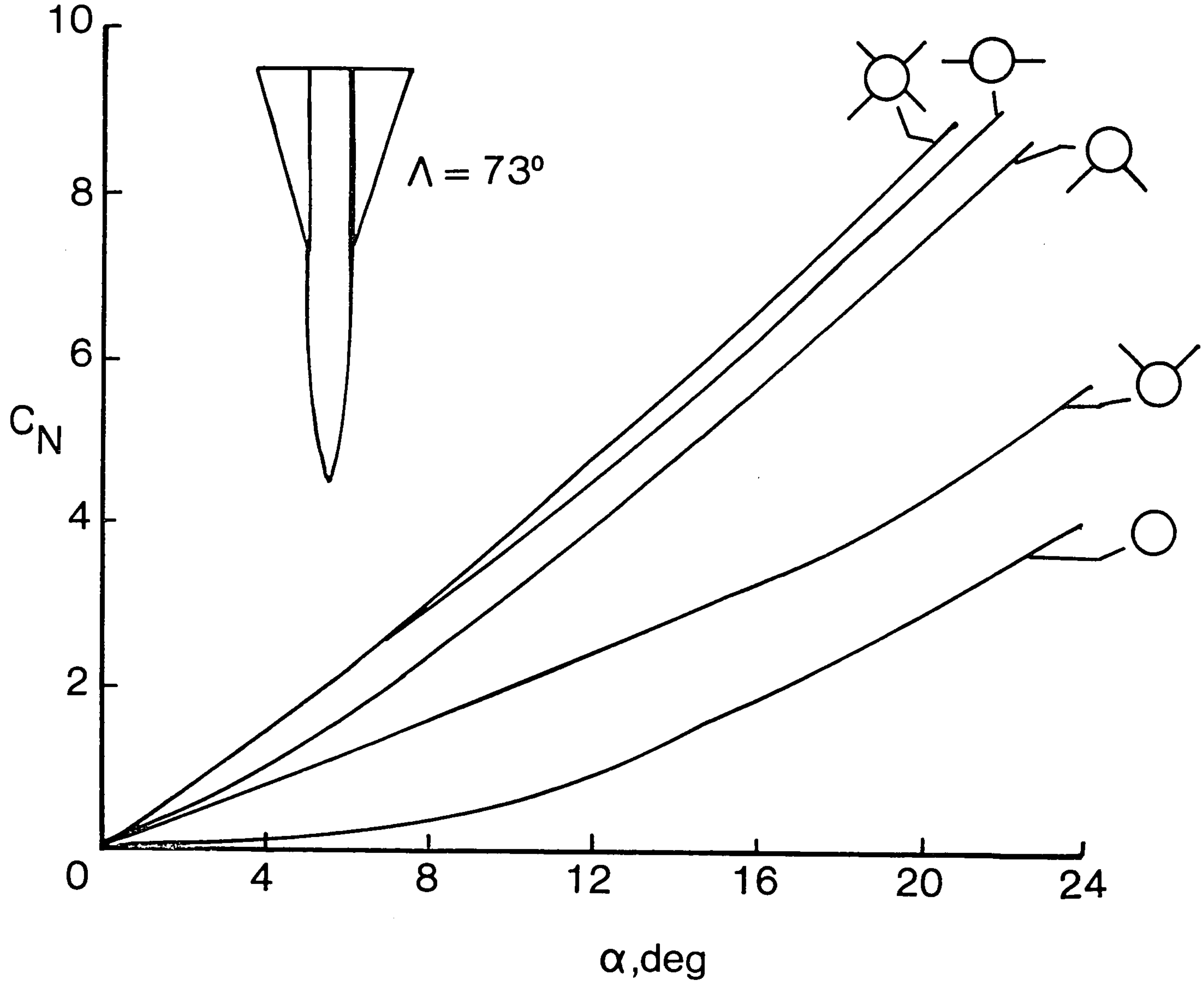


Figure 2.- Effect of wings on the normal force for a delta-wing-body concept at M = 2.

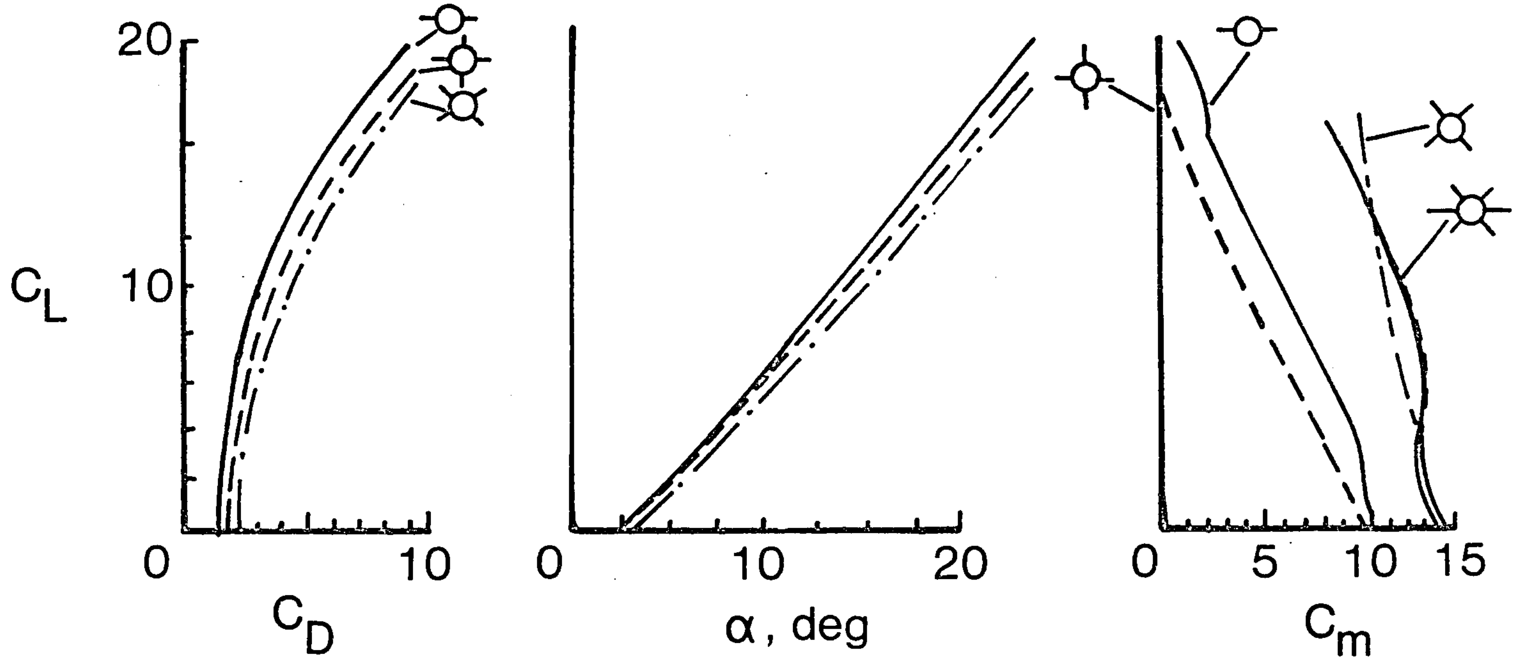


Figure 3.- Aerodynamic characteristics for various arrangements of monoplanar and cruciform versions of a delta-wing-body tail concept, M = 2.4, δ = -20°. c.g. = 0.60_l.

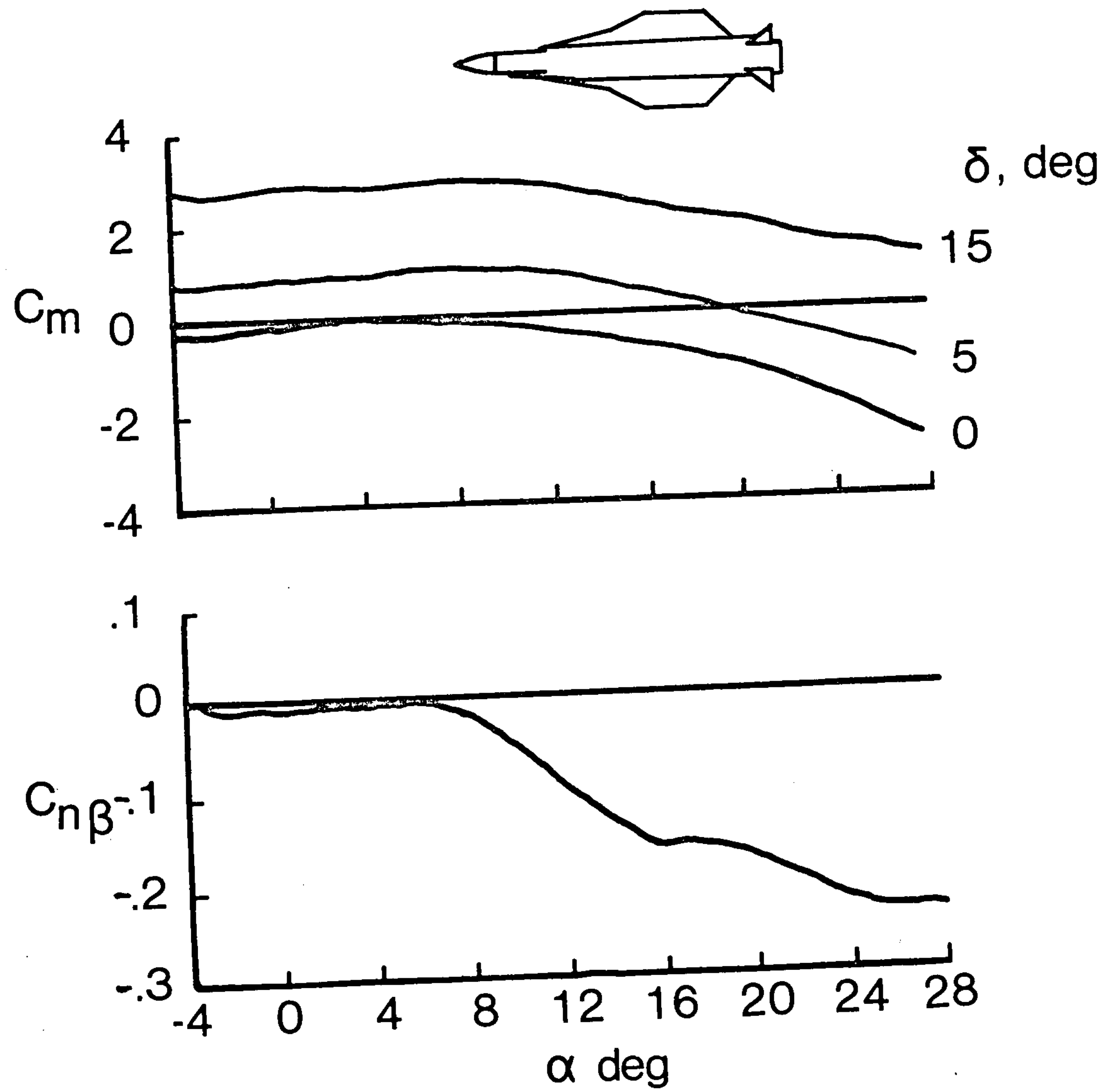


Figure 4.- Longitudinal-directional characteristics for a monoplanar missile with a cranked wing, an elliptic body, and cruciform tails, M = 2.86, c.g. = 0.59_l.

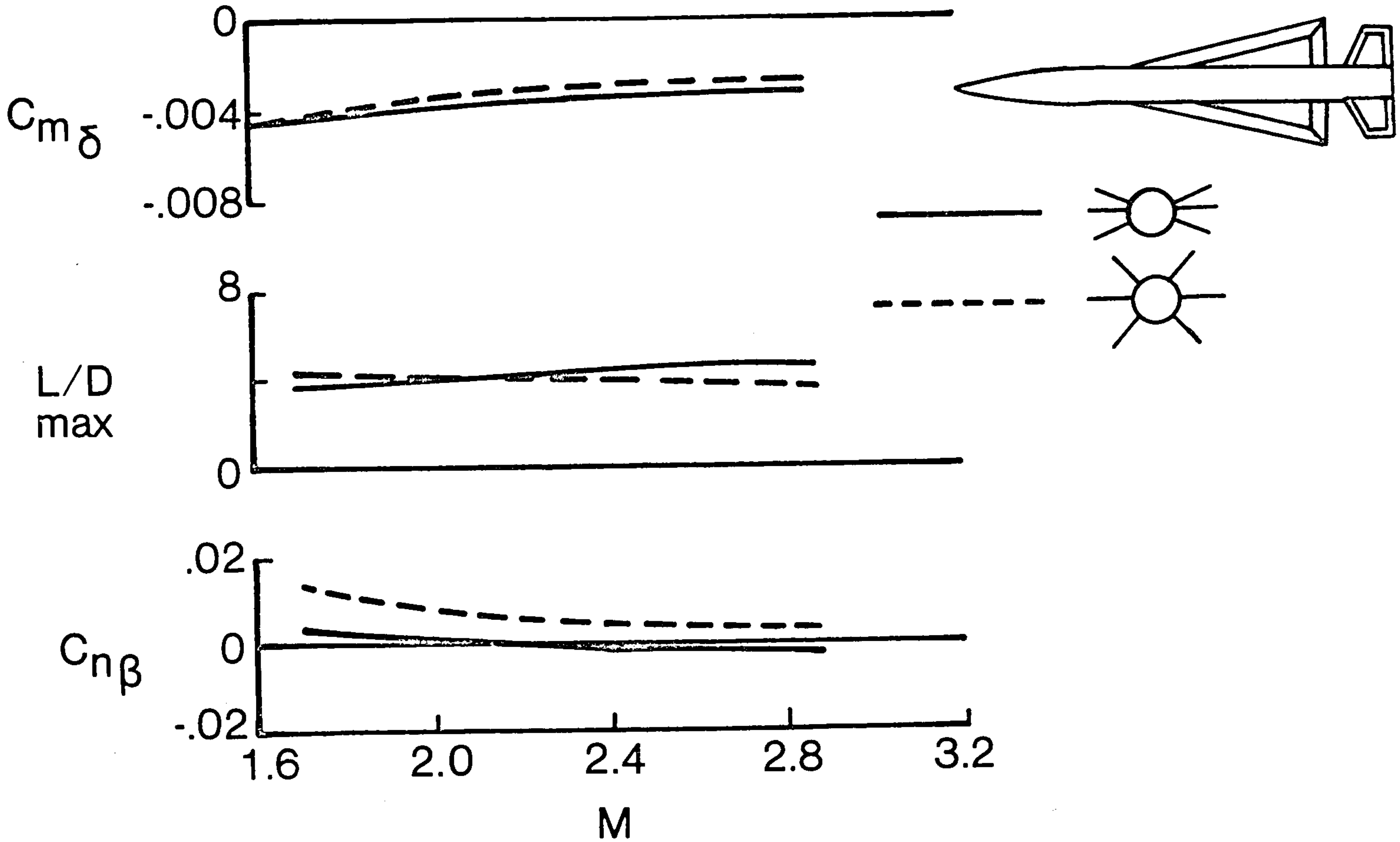


Figure 5.- Effect of low profile cruciform tails on a delta wing monoplanar missile, c.g. = 0.60_l.

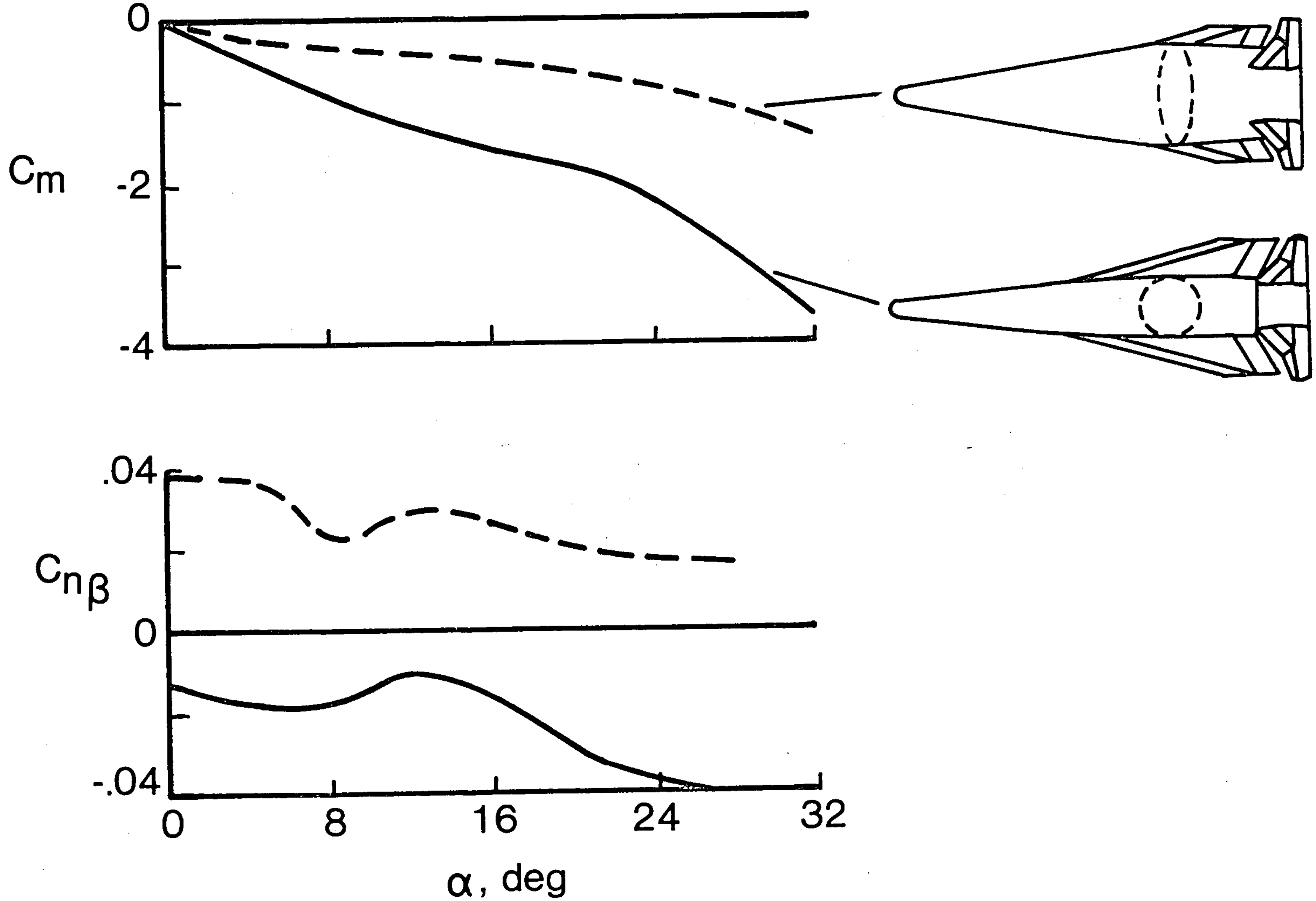


Figure 6.- Longitudinal-directional characteristics for a monoplanar swept wing missile with circular and elliptic body, M = 2.50, c.g. = 0.60_l.

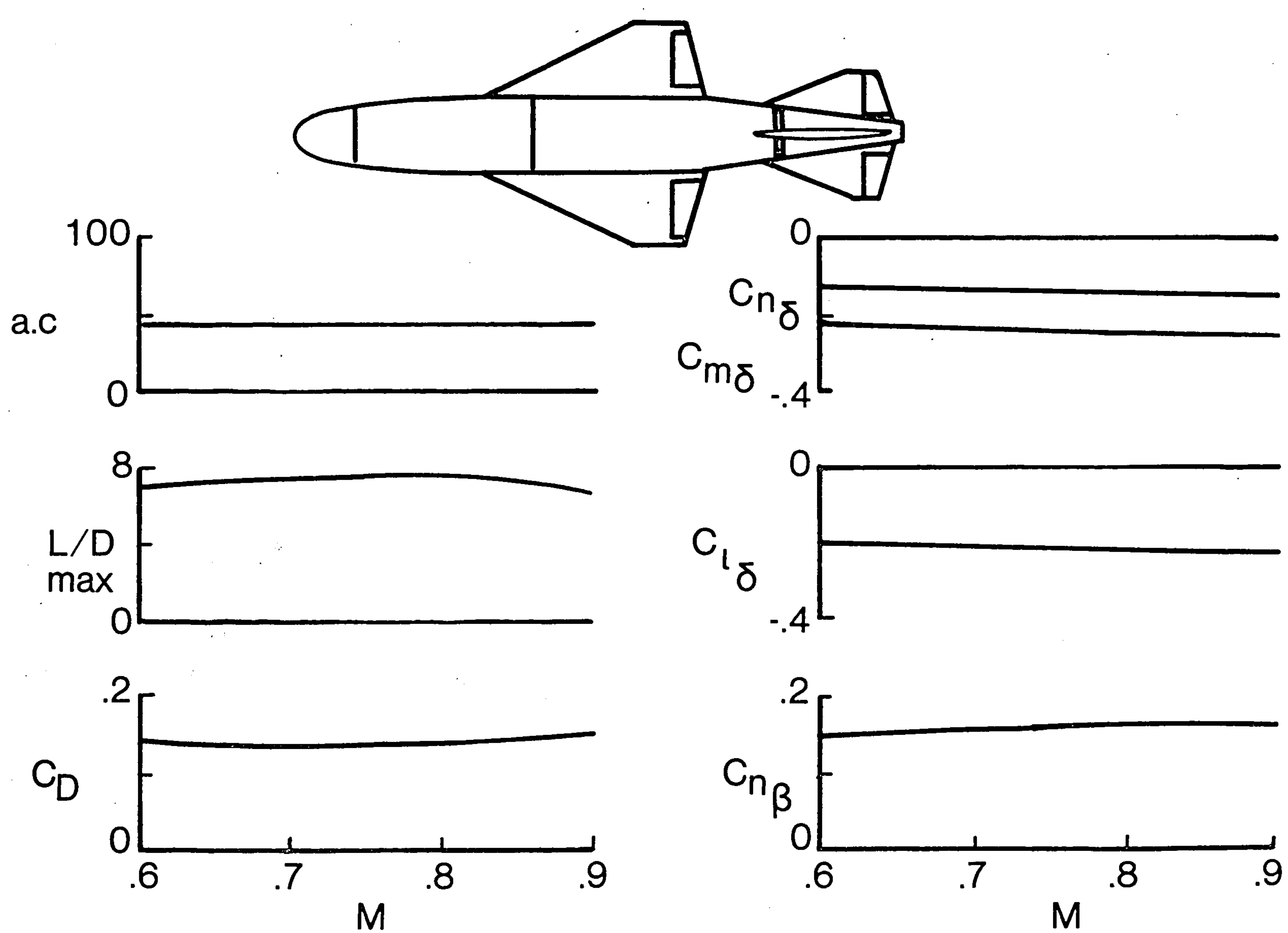


Figure 7.- Subsonic cruise missile characteristics.

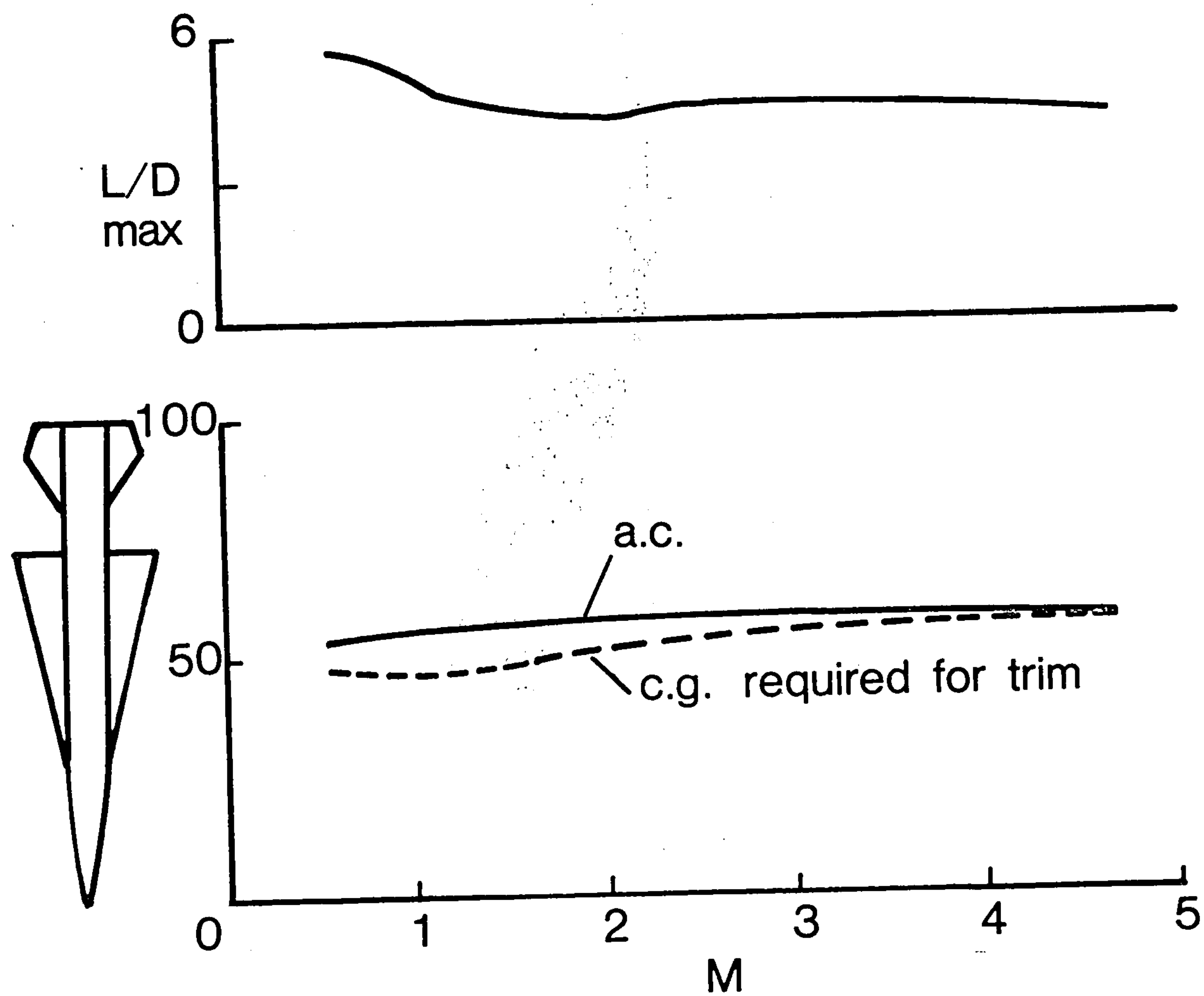


Figure 8.- Supersonic cruise missile characteristics.

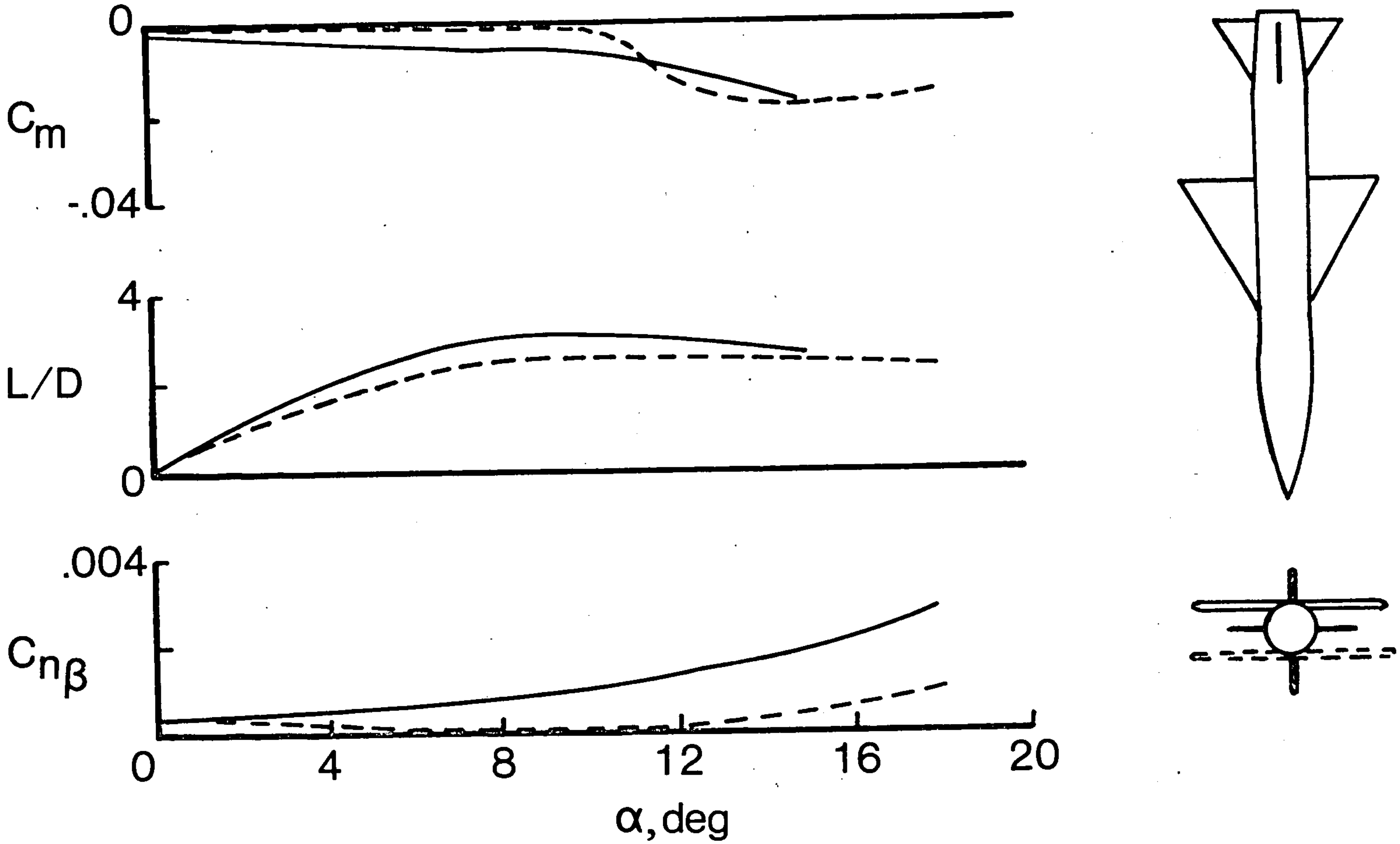


Figure 9.- Hypersonic cruise missile characteristics,
M = 5.2, c.g. = 0.50_l.

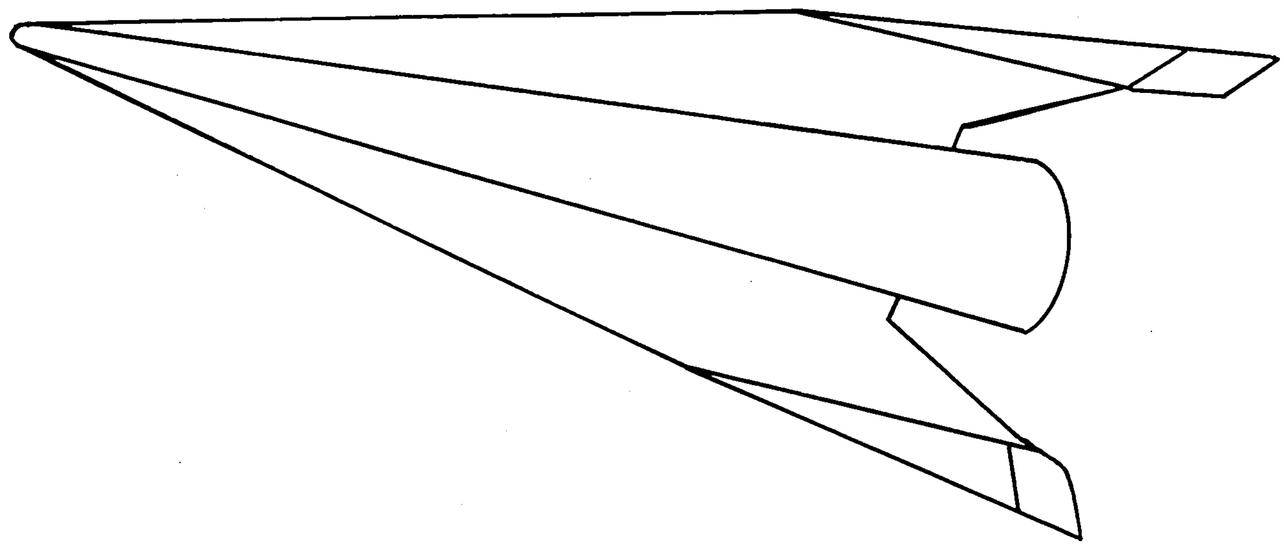


Figure 10.- A monoplanar arrow wing concept.

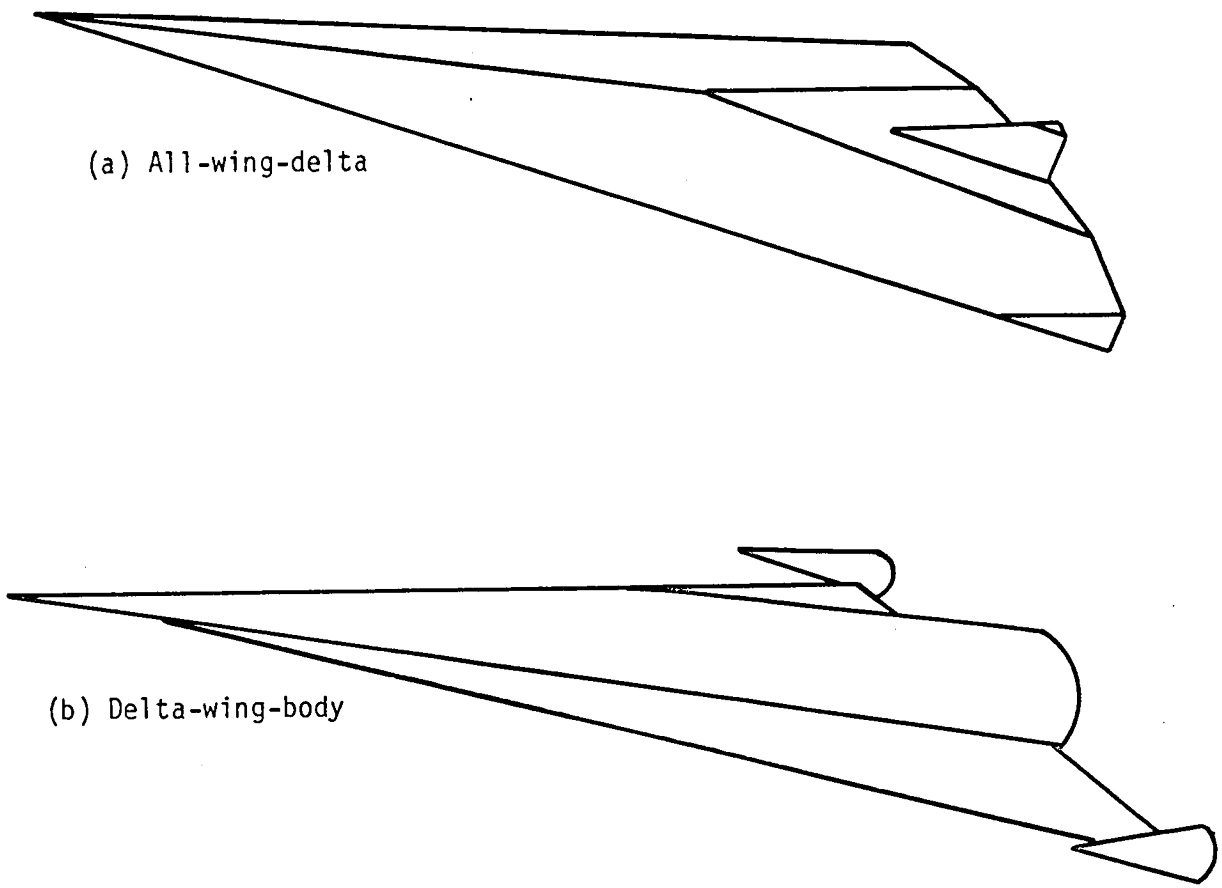
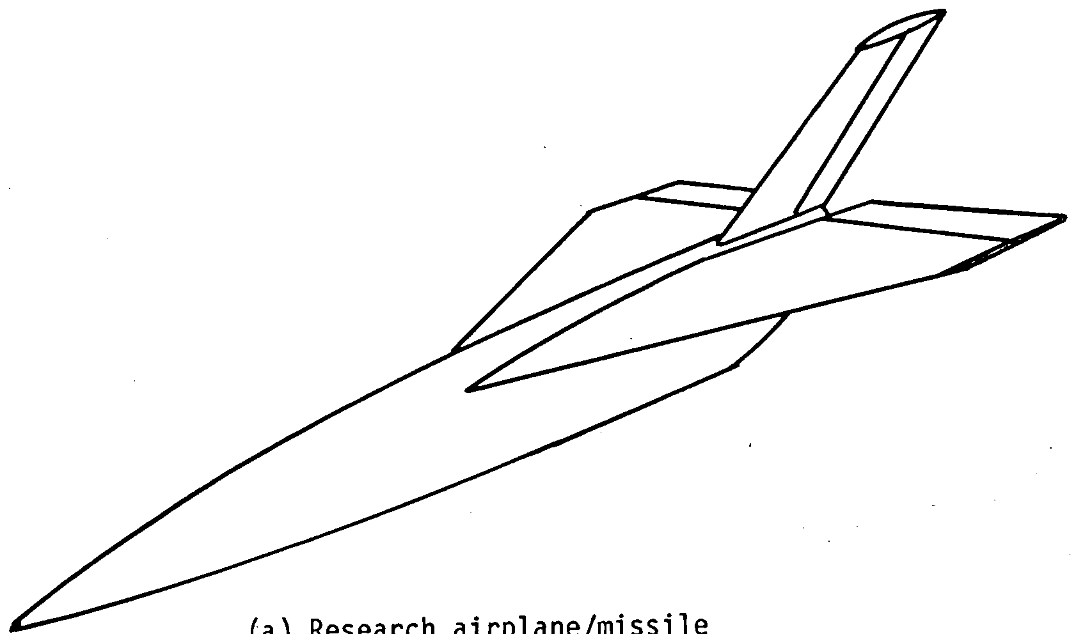
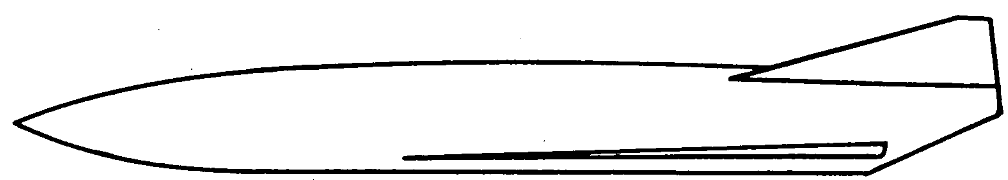


Figure 11.- Delta wing concepts.



(a) Research airplane/missile



(b) Airbreathing missile

Figure 12.- Hypersonic concepts.

1. Report No. NASA TM-86330	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN OVERVIEW OF SOME MONOPLANAR MISSILE PROGRAMS		5. Report Date December 1984
		6. Performing Organization Code 505-43-43-01
7. Author(s) M. Leroy Spearman		8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Virginia 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Colateral release with paper presented at the Joint Service Guidance and Control Committee Workshop on Bank-to-Turn Controlled Terminal Homing Missiles, Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, Sept. 19-20, 1984.

16. Abstract

A historical review is presented of some monoplanar missile systems in which the vehicle flight control was similar to that for a conventional aircraft. The review is essentially chronological, beginning prior to World War I, and includes worldwide programs. Illustrative examples of aerodynamic research with monoplanar missiles are presented including some comparisons with cruciform missiles. Some examples of current programs are presented and some particular mission applications for monoplanar systems are discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Missiles Monoplanes	Unclassified-Unlimited Subject Category 01

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	32	A03

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161