United States Patent [19]
Goss et al.

[11] **3,908,933**
[45] **Sept. 30, 1975**

[54] GUIDED MISSILE

[75] Inventors: **Wilbur H. Goss,** Silver Spring, Md.; **Henry H. Porter; Richard B. Roberts,** both of Washington, D.C.; **Merle Antony Tuve,** Chevy Chase. Md.; **Jesse W. Beams,** Charlottesville, Va.; **Harner Selvidge,** Detroit, Mich.

[73] Assignee: **The United States of America as represented by the Secretary of the** Navy, Washington, D.C.

[22] Filed: **June 26, 1956**

[21] Appl. No.: **594,067**

[52] **U.S. Cl.** **244/3.21;** 60/270
[51] **Int. Cl.^{2}** **F42B 15/02**
[58] **Field of Search** 244/14, 3.21; 114/20.1; 343/7, 7.3; 102/50, 49; 60/270

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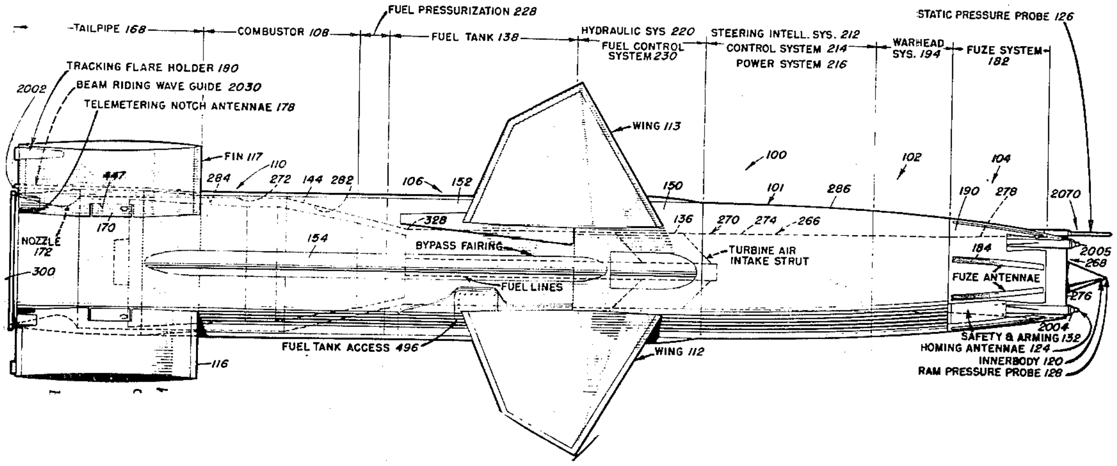
Radar Guided Missile, Wireless World, Feb. 1956, pp. 67–70.

Primary Examiner—Verlin R. Pendegrass
Attorney, Agent, or Firm—R. S. Sciascia; J. S. Lacey; W. G. Finch

EXEMPLARY CLAIM

1. An aerial missile including, in combination, an airframe comprising a plurality of connected body assemblies having duct sections defining a duct extending throughout the length of the body and having a wall, said wall providing an inlet, a diffuser communicating with the inlet, a combustion chamber communicating with the diffuser and an exit nozzle communicating with the combustion chamber, a cowl lip connecting the forwardmost body assembly and the wall of the forwardmost duct section at their corresponding forward ends, wings on the airframe and mounted for rocking movement about their root axes, longitudinally spaced partitions surrounding the duct wall and defining a compartment, an explosive charge in the compartment and surrounding the duct, a fuze system for the charge, and means mounted on one of the partitions and operable for imparting rocking movement to the wings.

25 Claims, 110 Drawing Figures



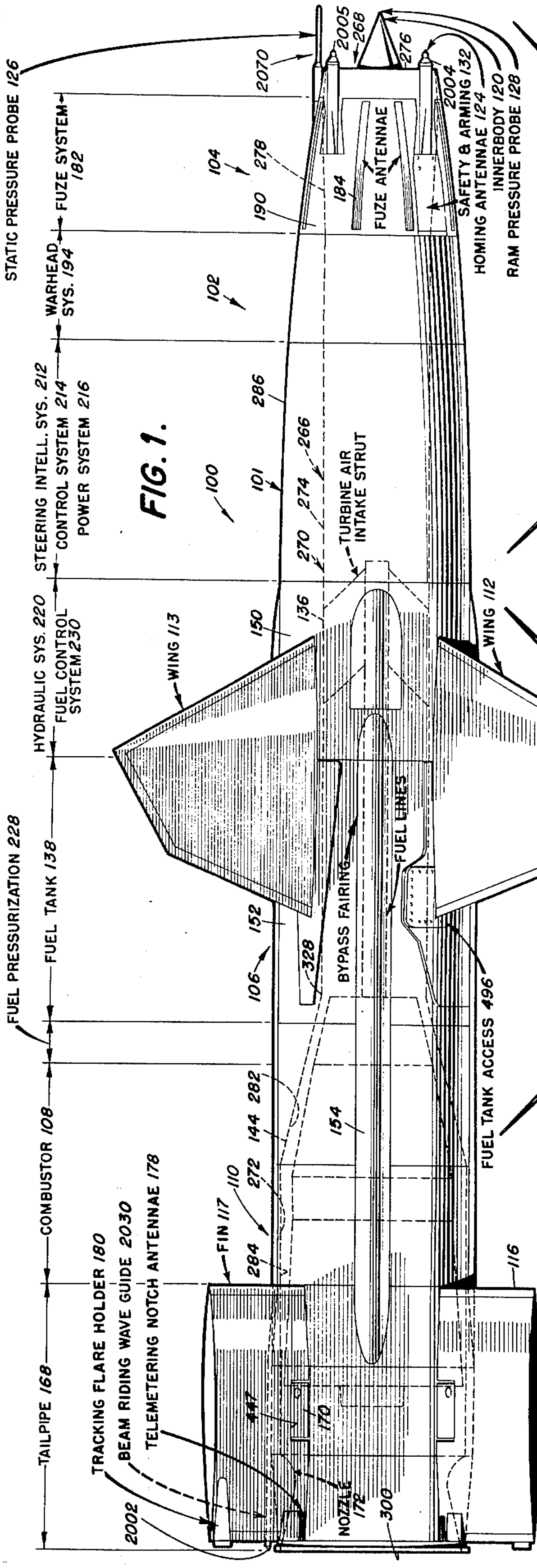


FIG. 1.

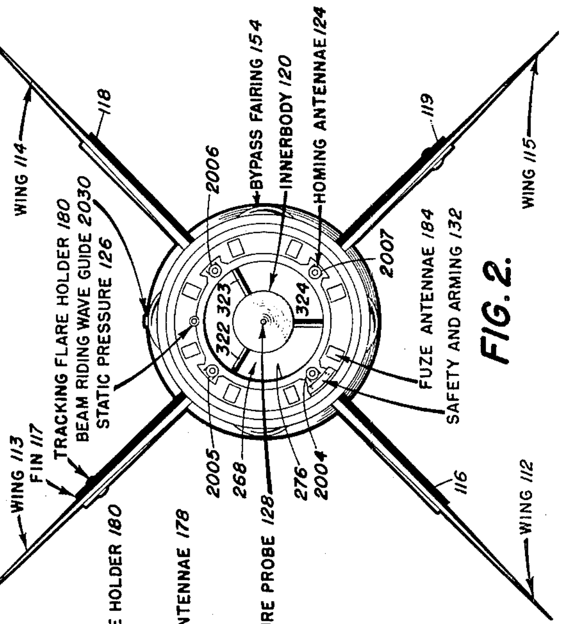


FIG. 2.

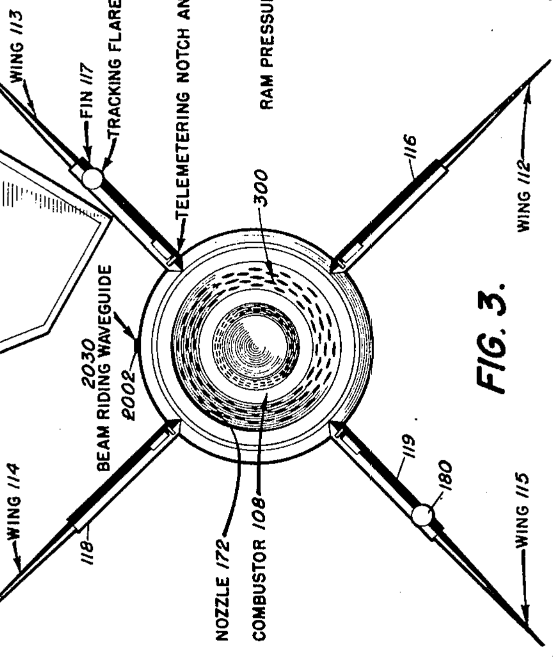


FIG. 3.

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HARNER SELVIDGE
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INVENTORS

WITNESSES:
Thaddeus Stepek
Evelyn A. Stevenson

BY Walter G. Finch

ATTORNEY

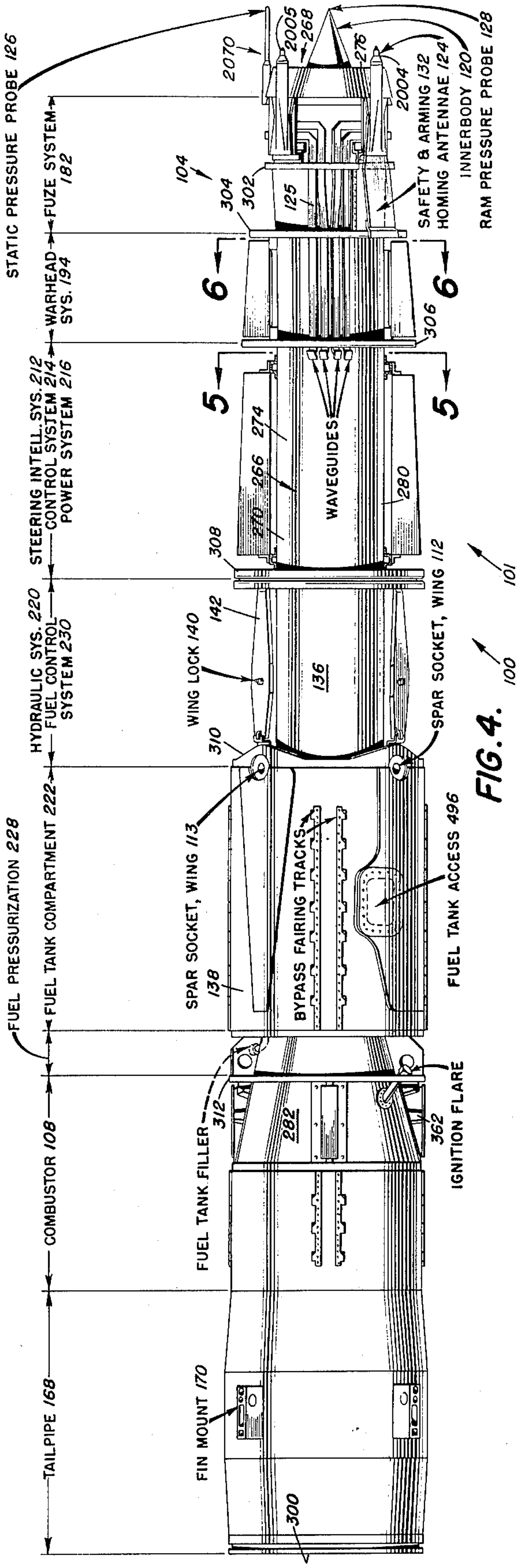

FIG. 4.

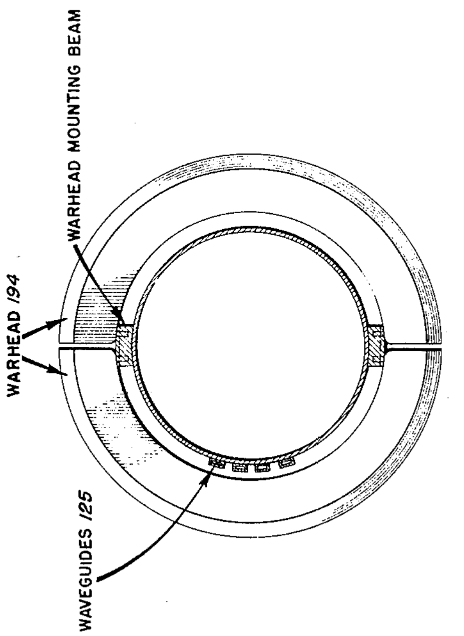

FIG. 6.

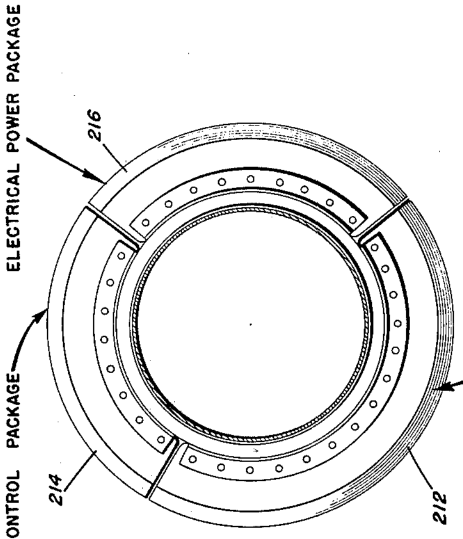

FIG. 5.

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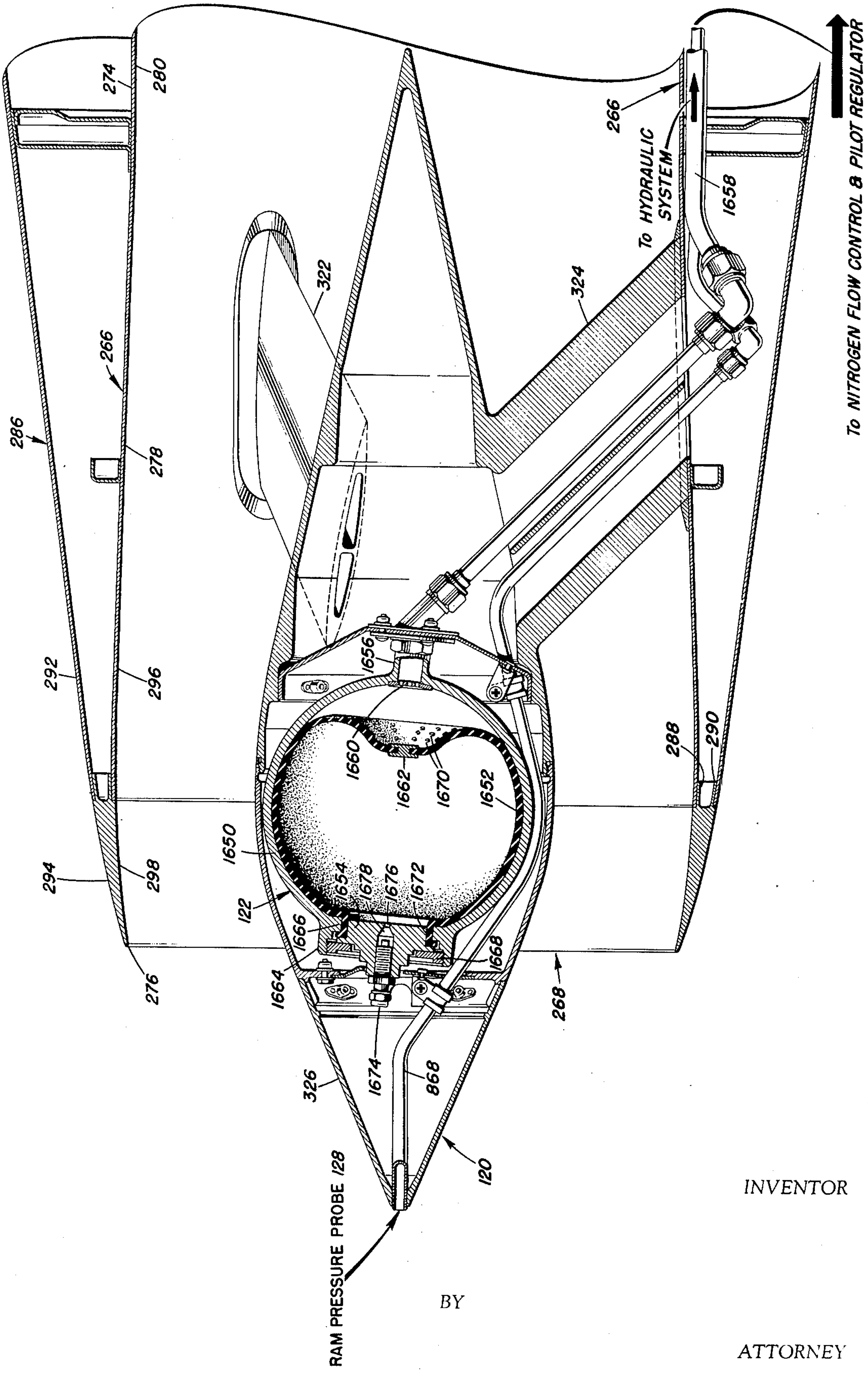
FIG. 7.



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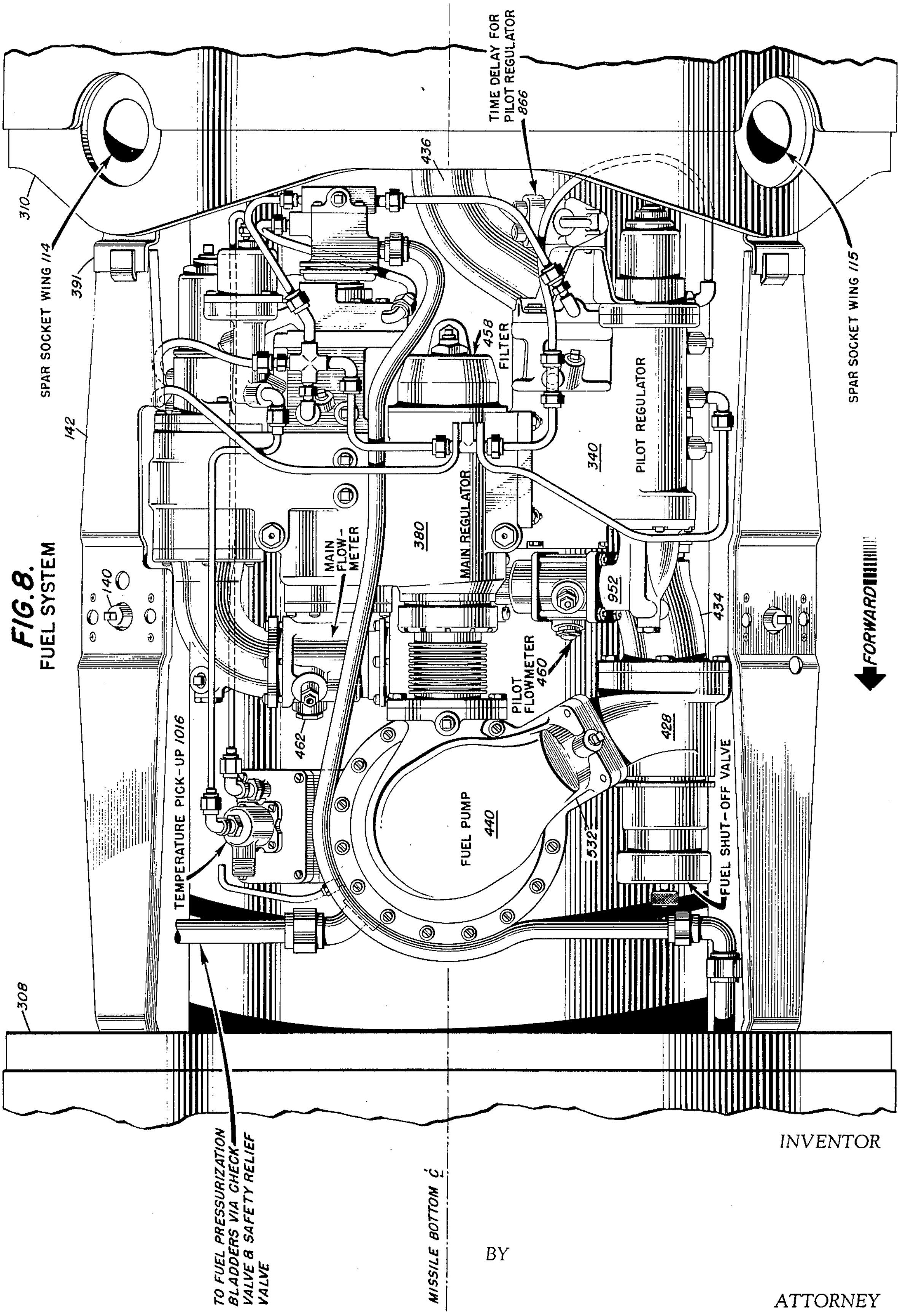

FIG. 8.
FUEL SYSTEM

INVENTOR

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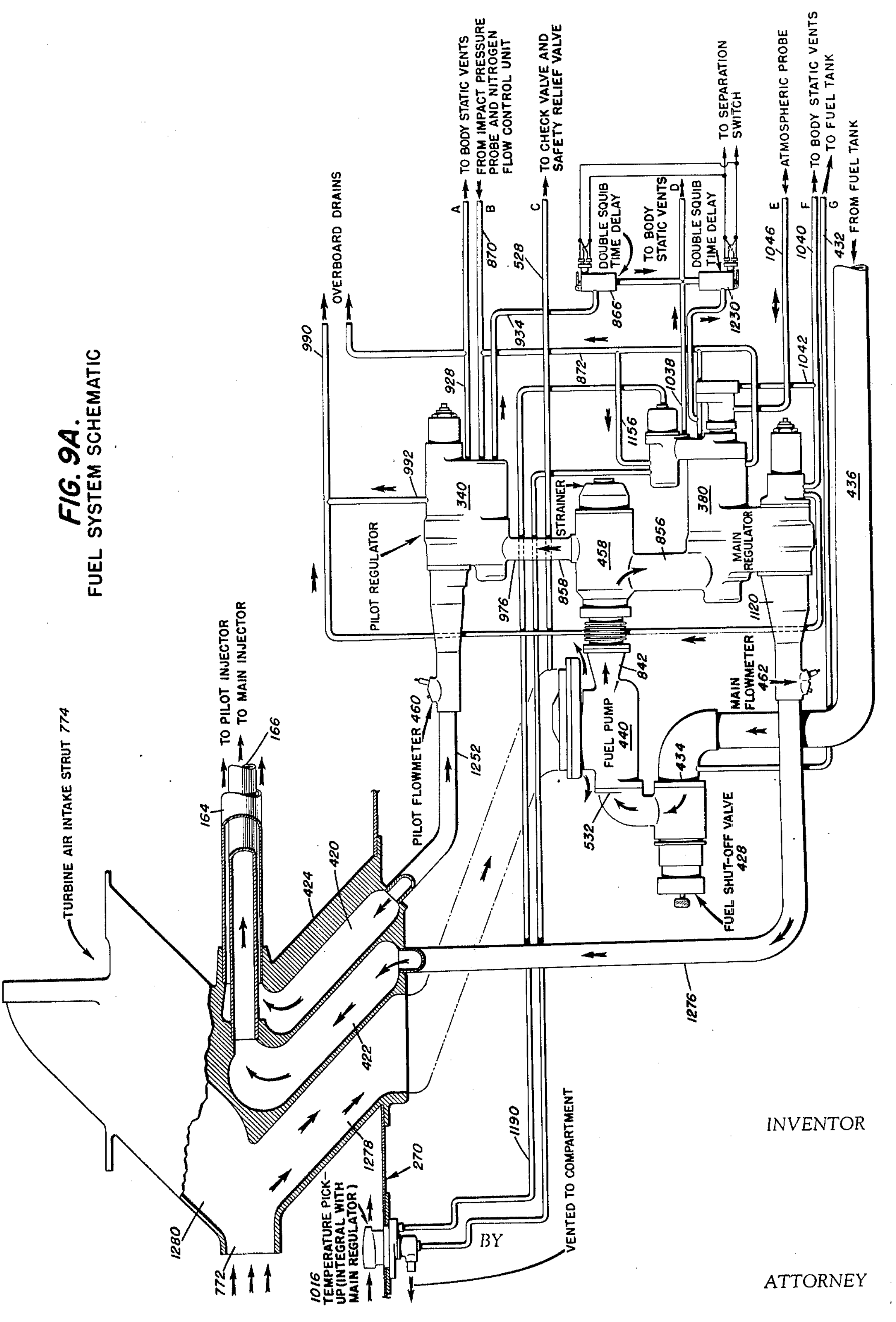
FIG. 9A.
FUEL SYSTEM SCHEMATIC



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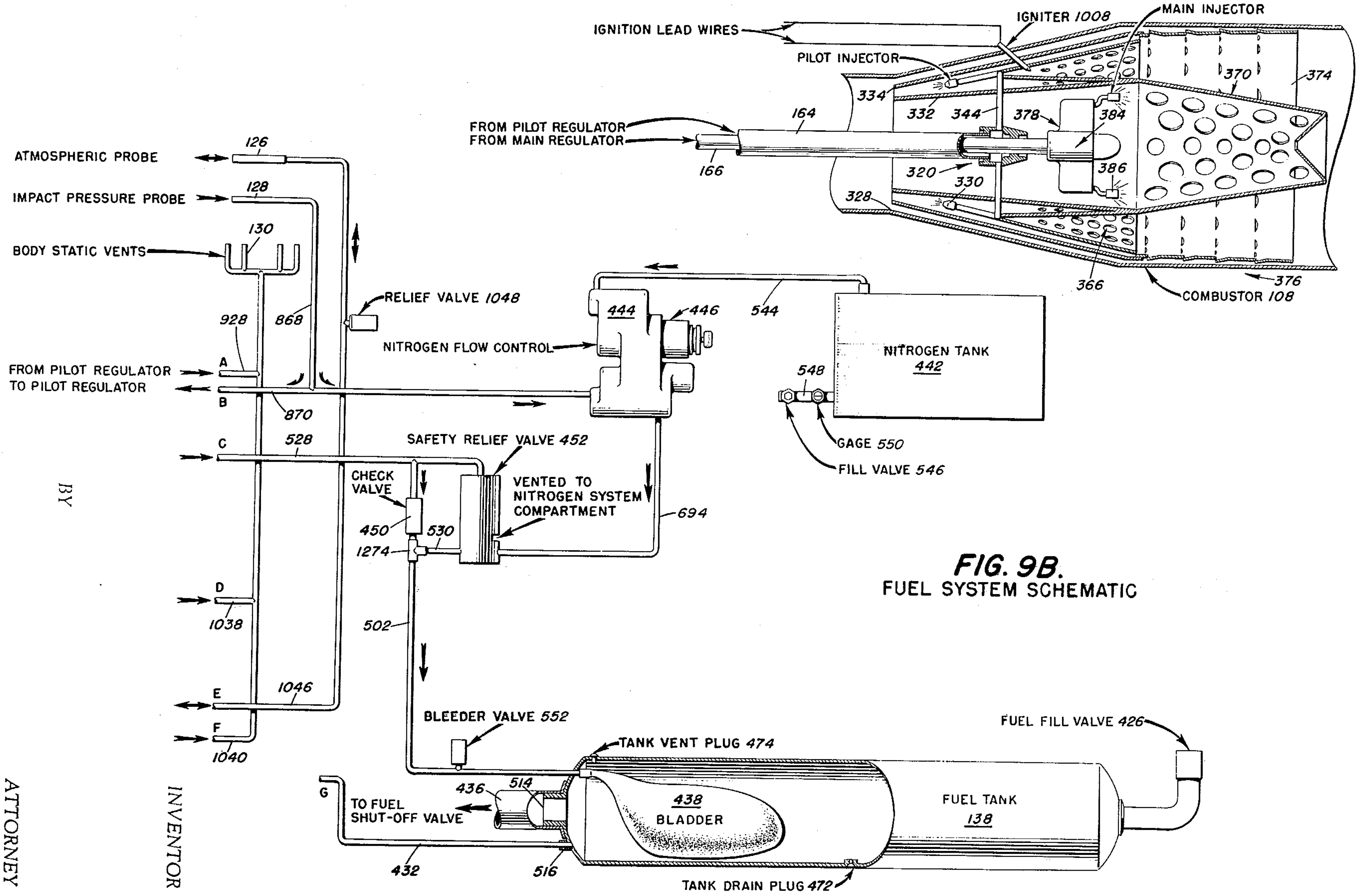

FIG. 9B.
FUEL SYSTEM SCHEMATIC

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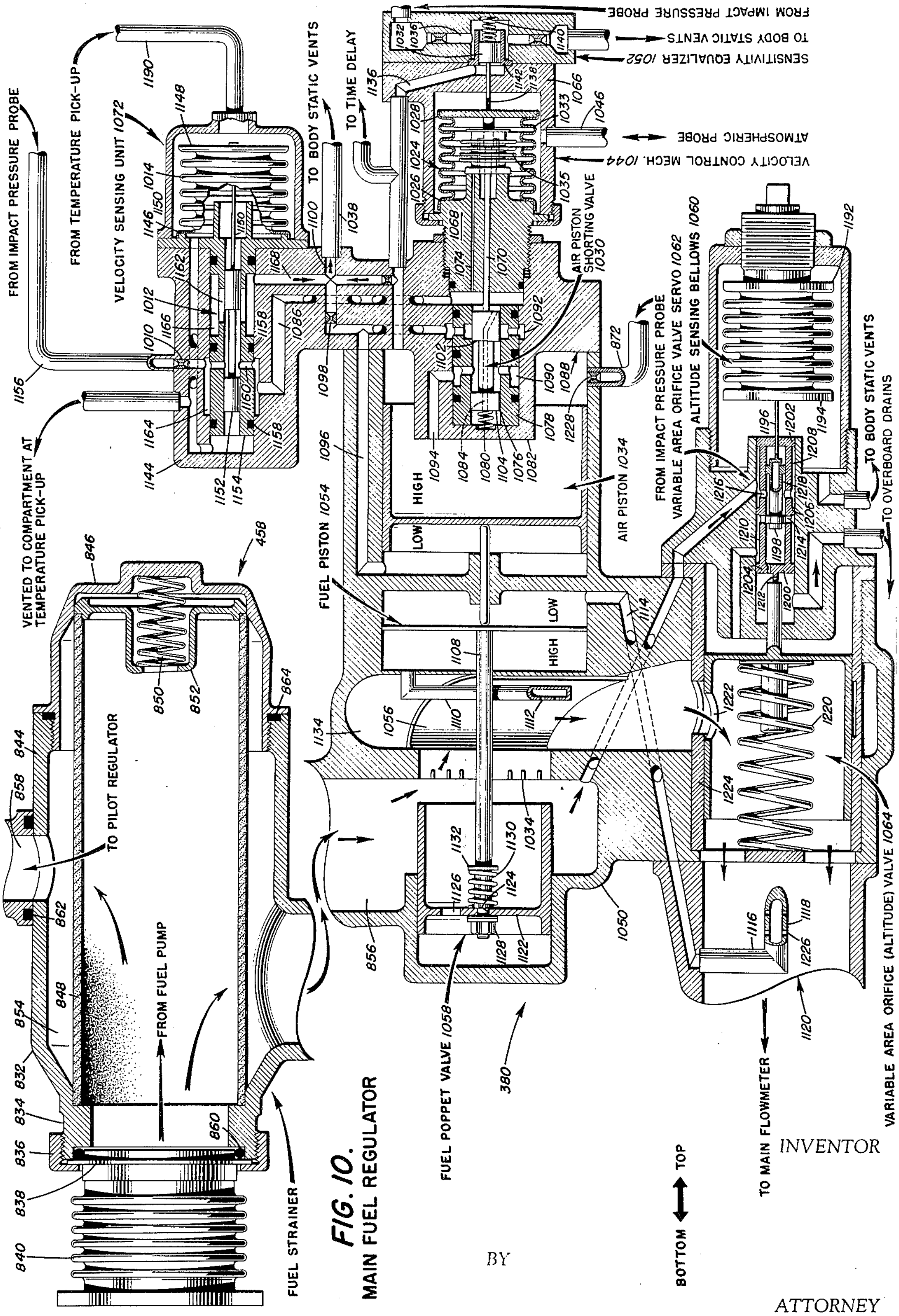

FIG. 10.
MAIN FUEL REGULATOR

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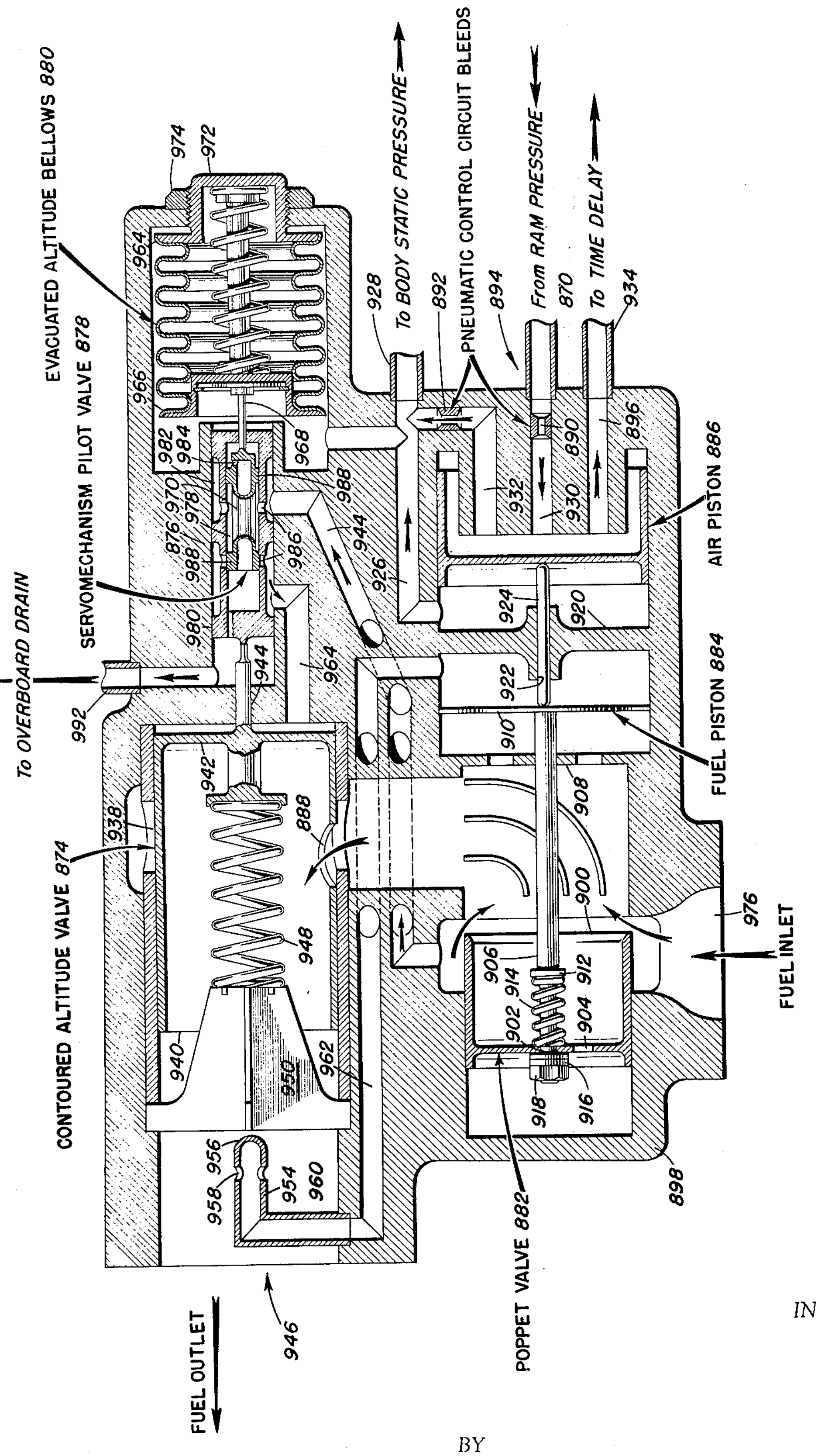

FIG. 11.
PILOT REGULATOR
Fuel Control System

INVENTOR

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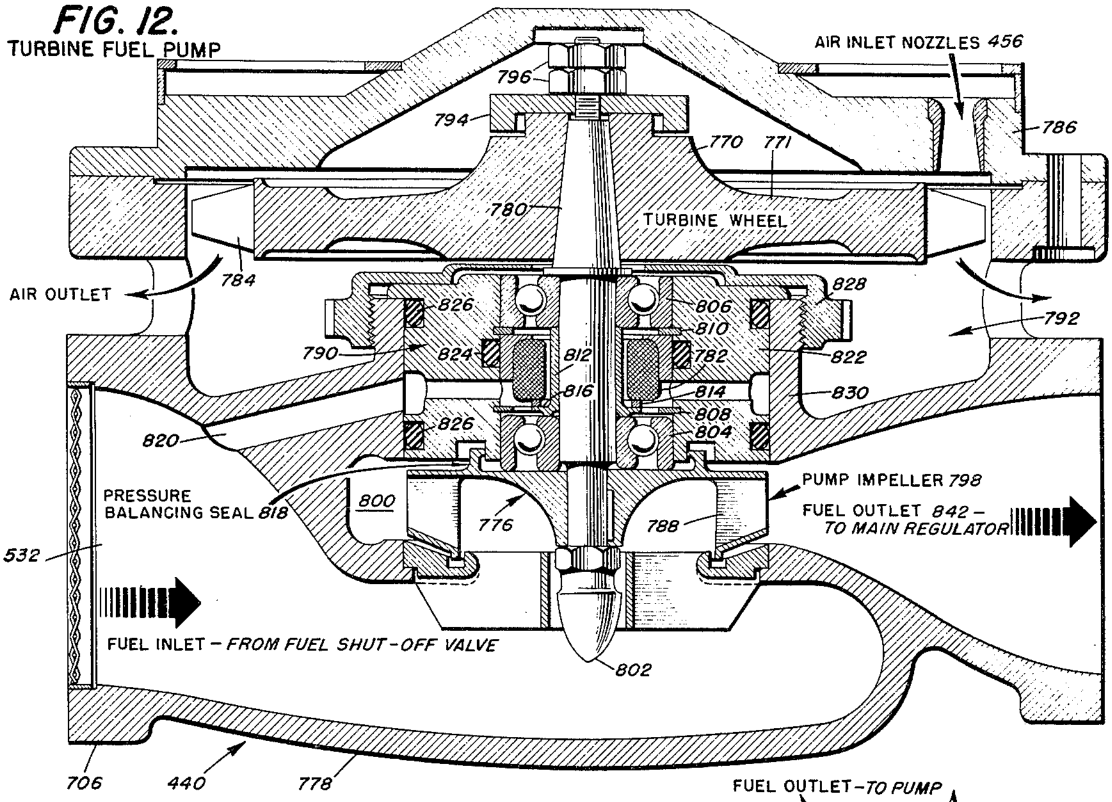
FIG. 12.
TURBINE FUEL PUMP



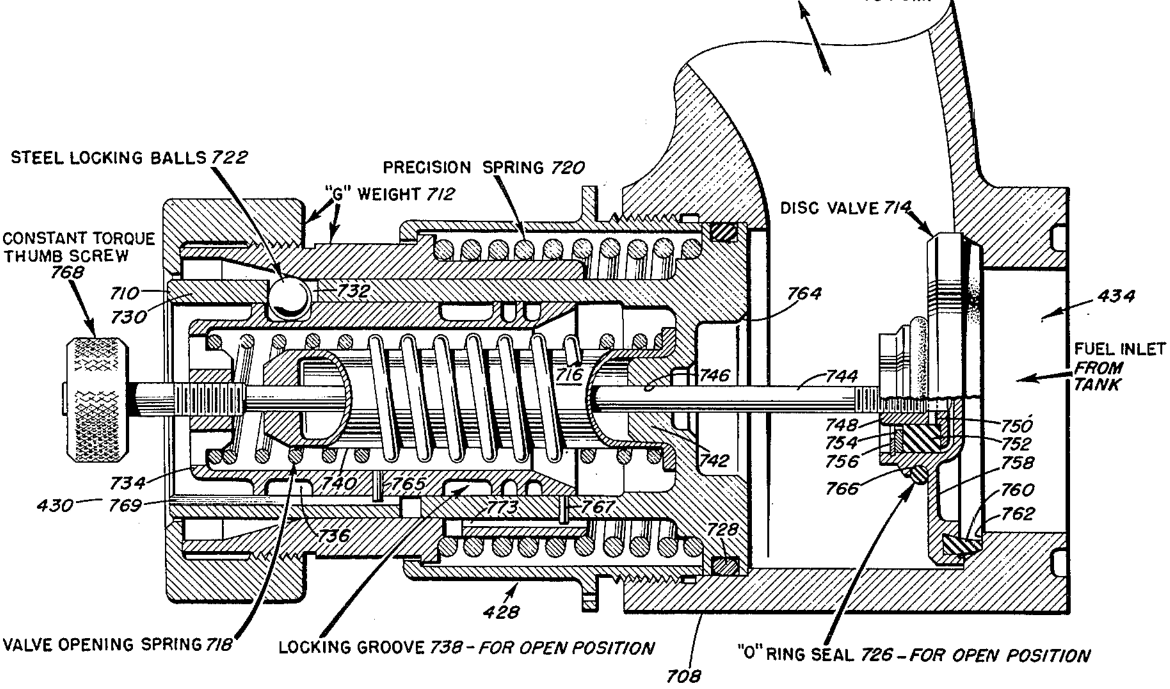


FIG. 13.
FUEL SHUT-OFF VALVE

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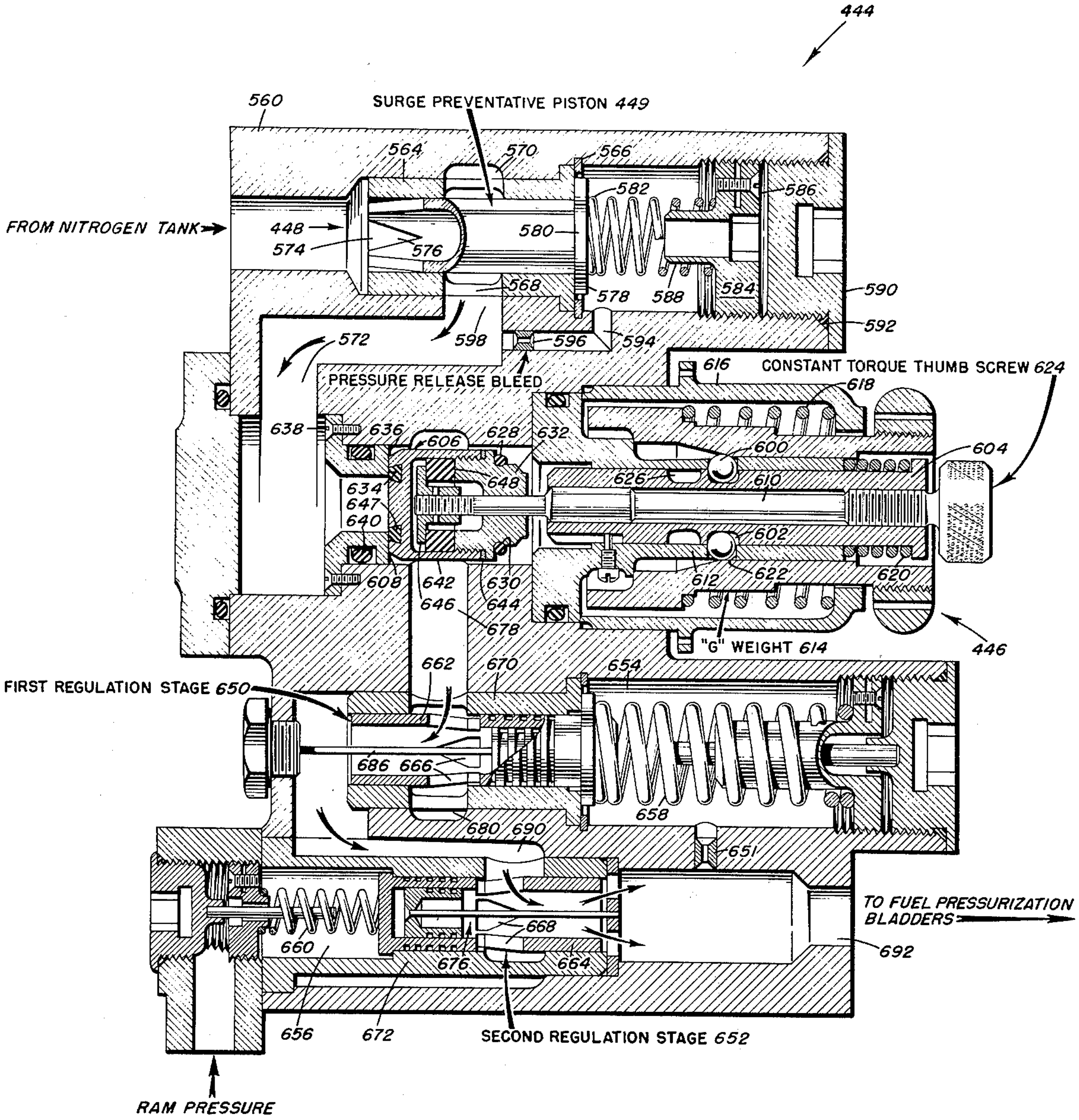
FIG. 14.

NITROGEN FLOW CONTROL UNIT
Fuel Pressurization System



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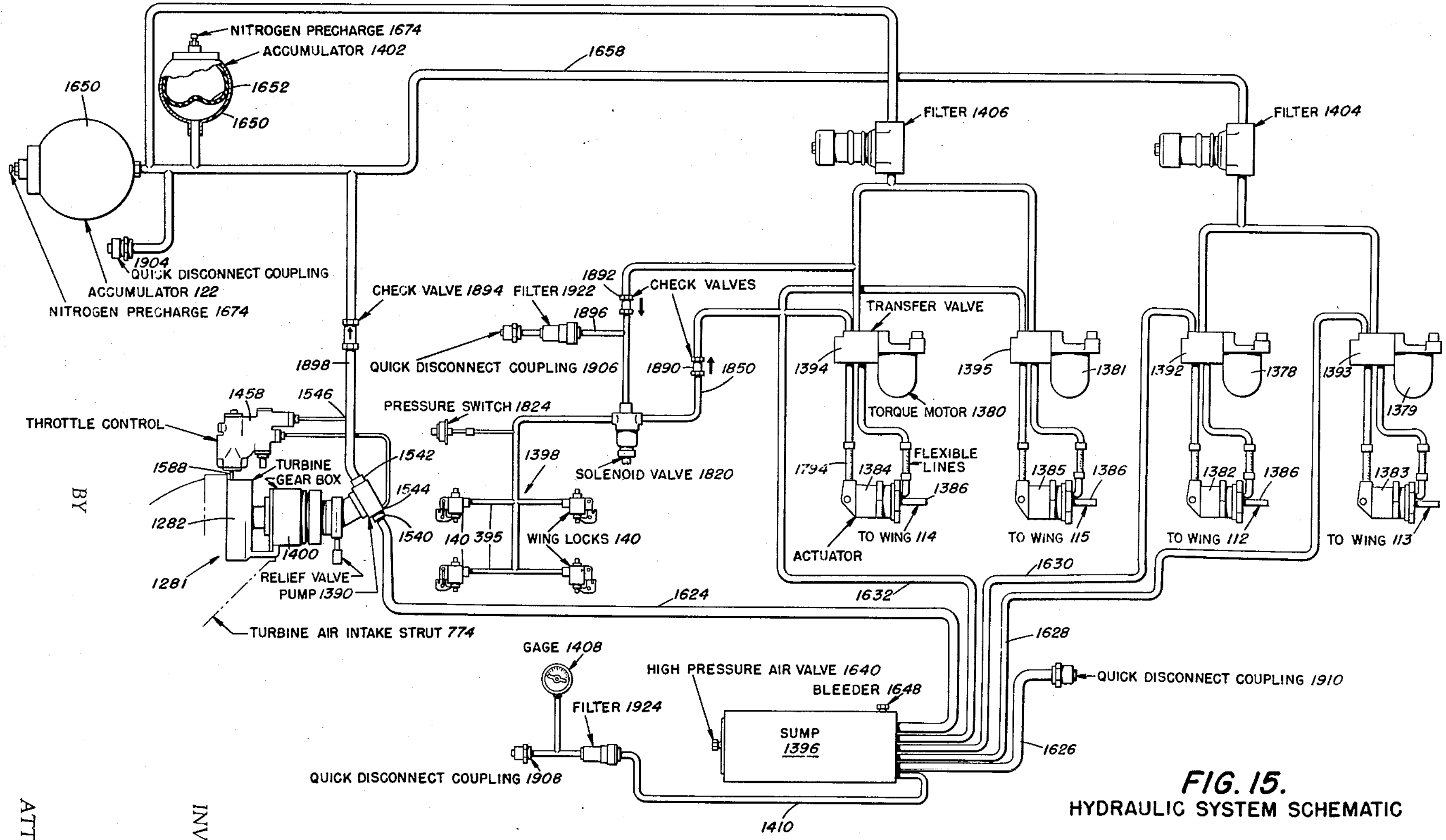

FIG. 15.
HYDRAULIC SYSTEM SCHEMATIC

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FIG. 16.
HYDRAULIC SYSTEM
(Packaging Arrangement)

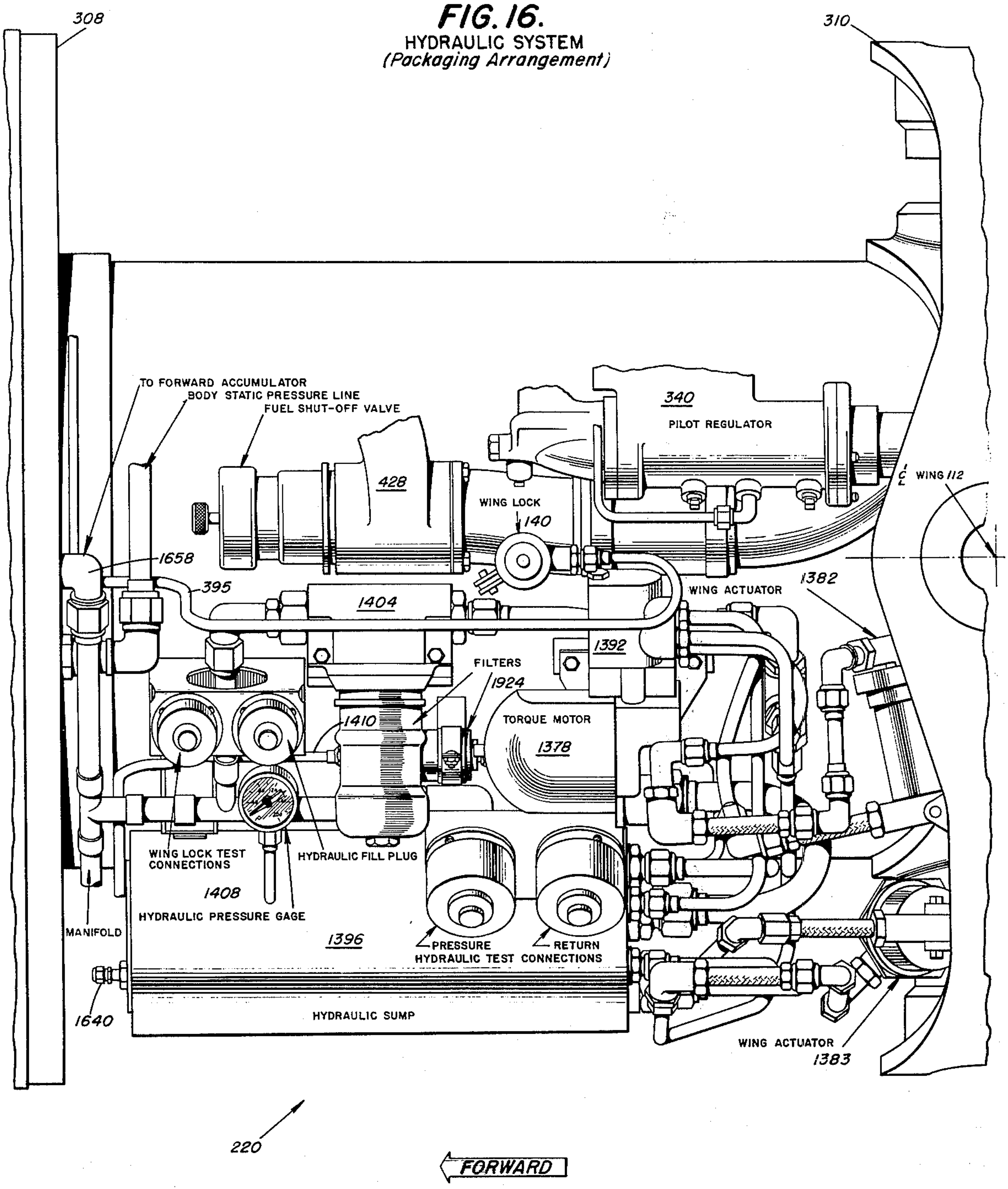

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FIG. 17.

HYDRAULIC SYSTEM
(Packaging Arrangement)

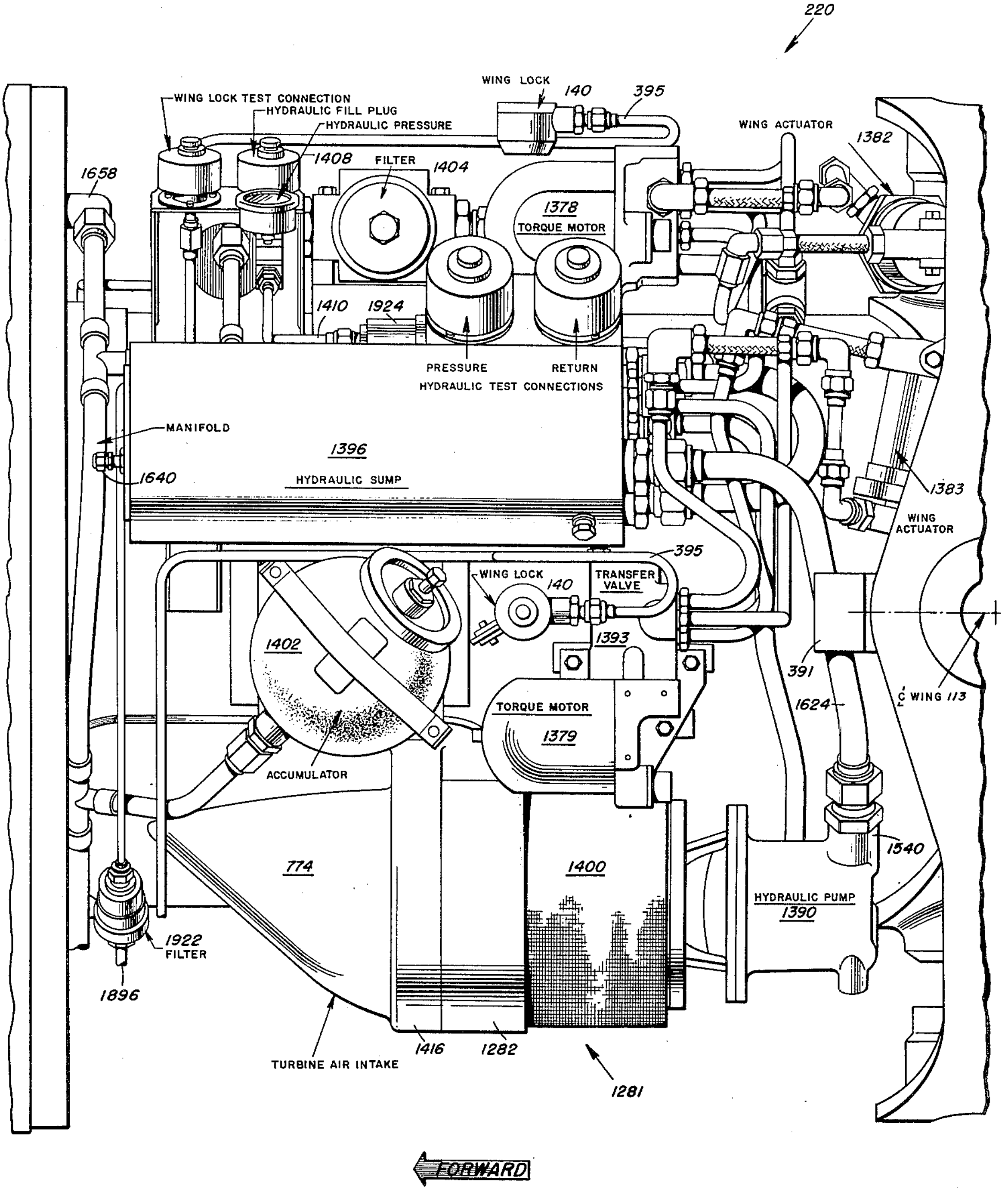

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FIG. 18.

HYDRAULIC SYSTEM
(Packaging Arrangement)

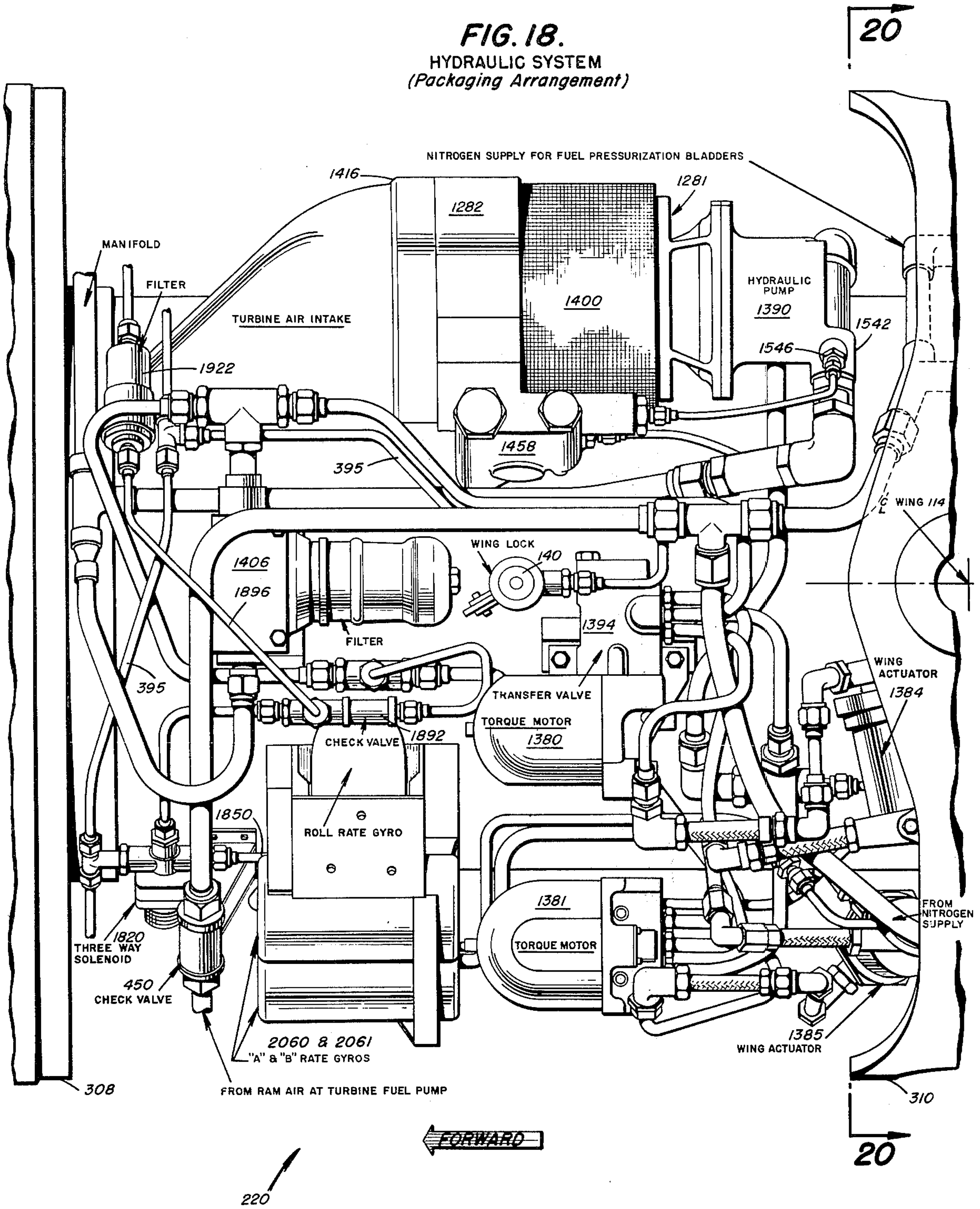

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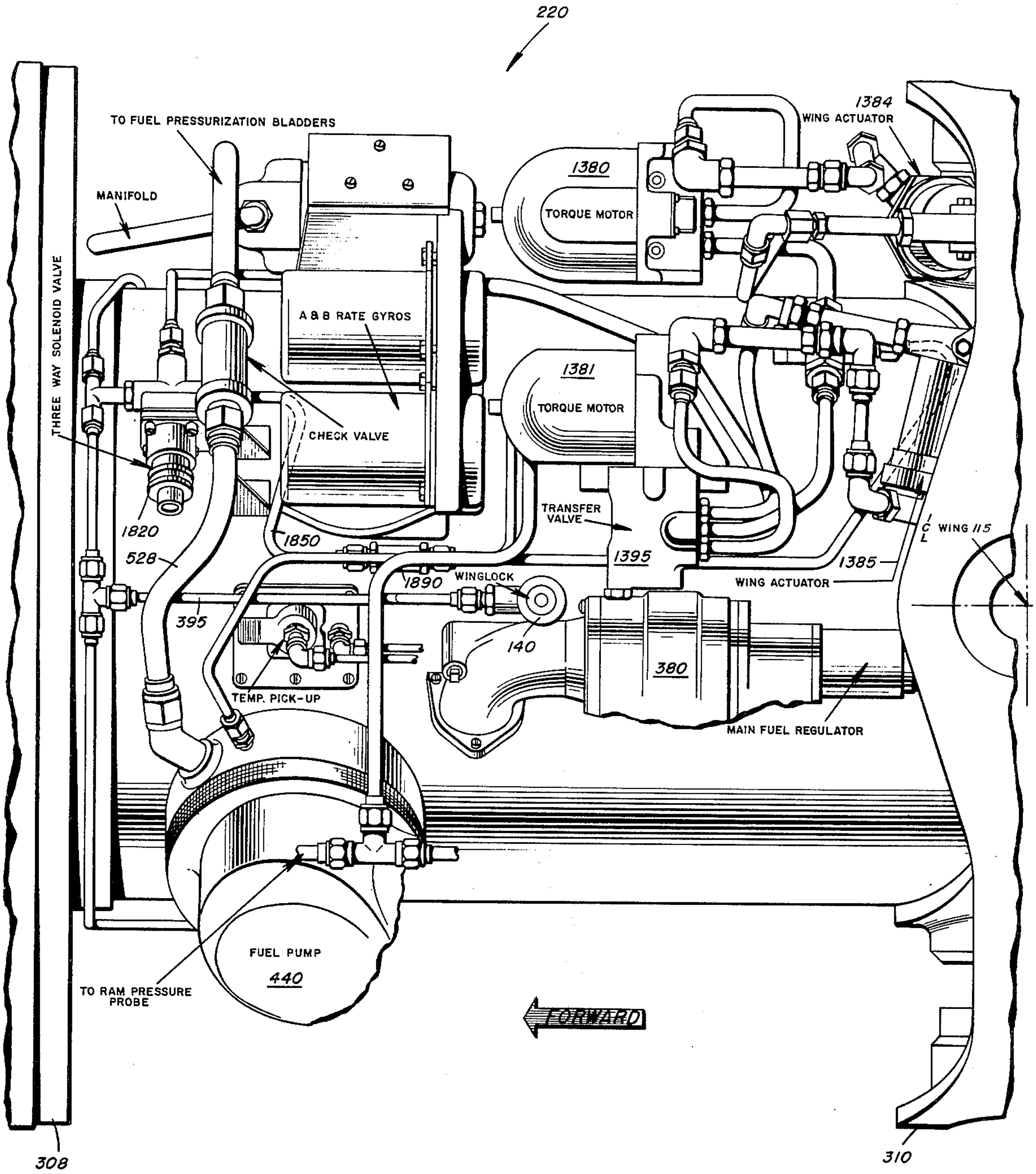
FIG. 19.

HYDRAULIC SYSTEM
(Packaging Arrangement)



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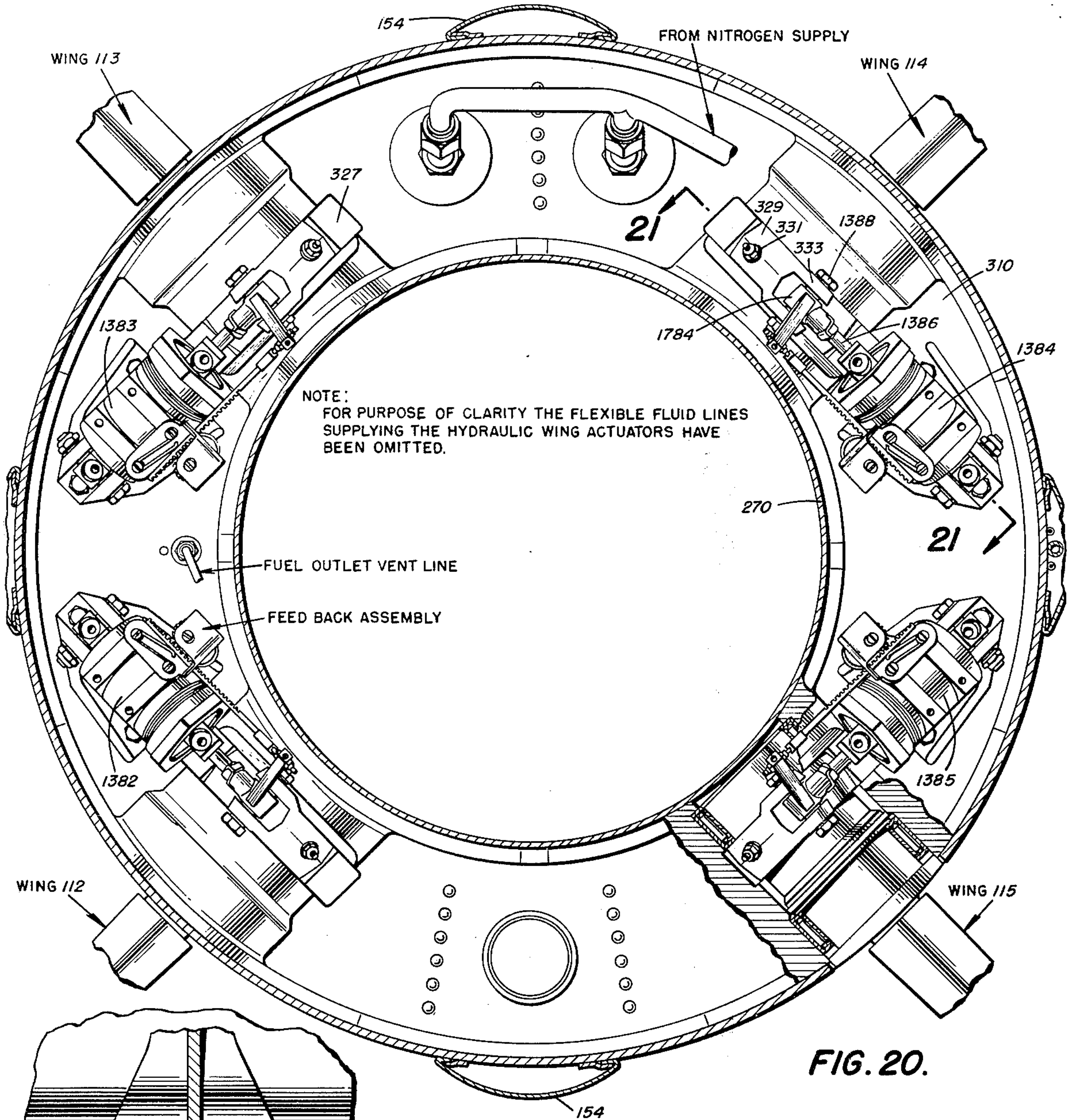

FIG. 20.

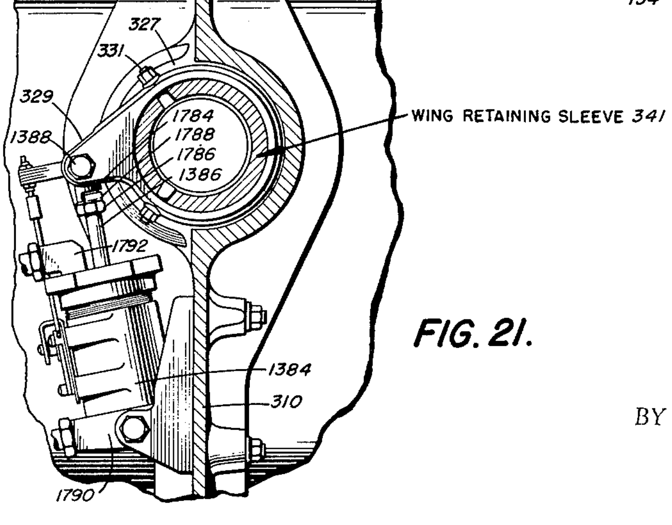

FIG. 21.

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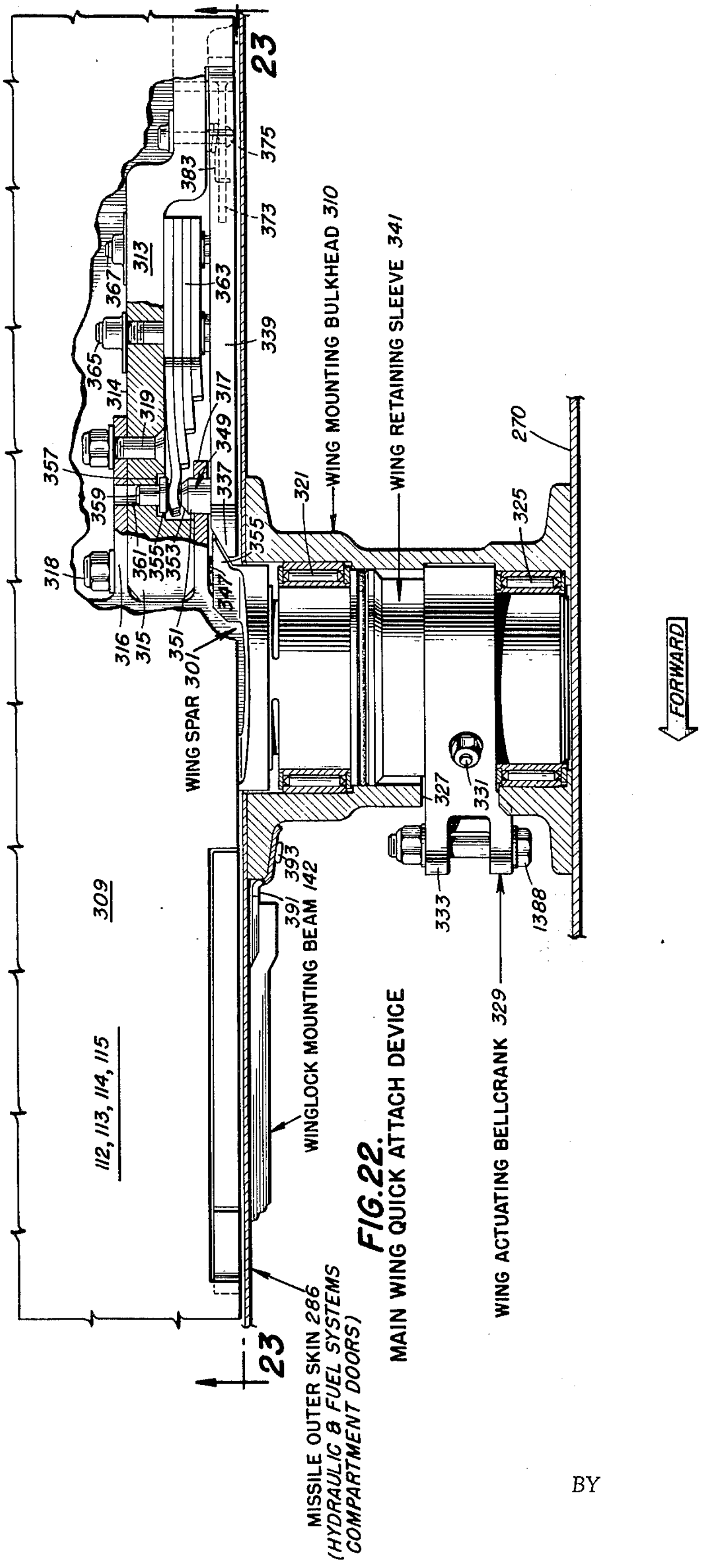

FIG.22.
MAIN WING QUICK ATTACH DEVICE

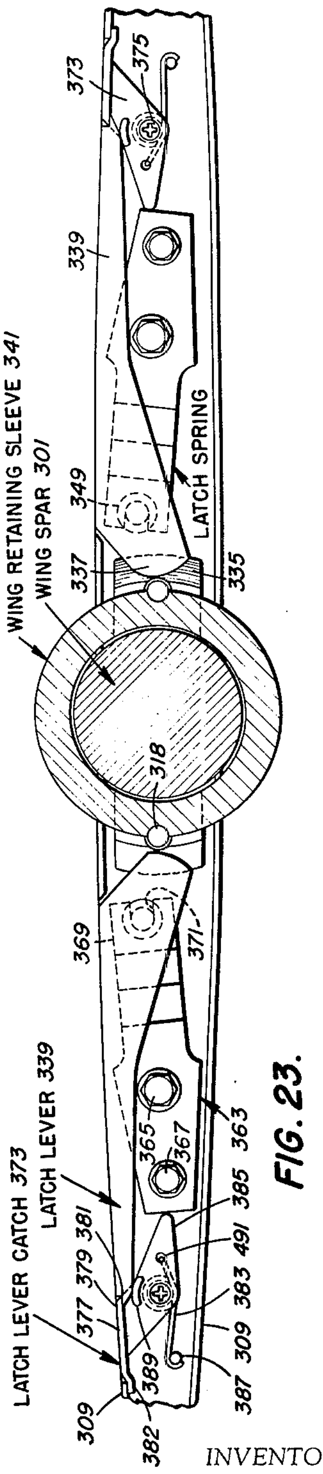

FIG. 23.

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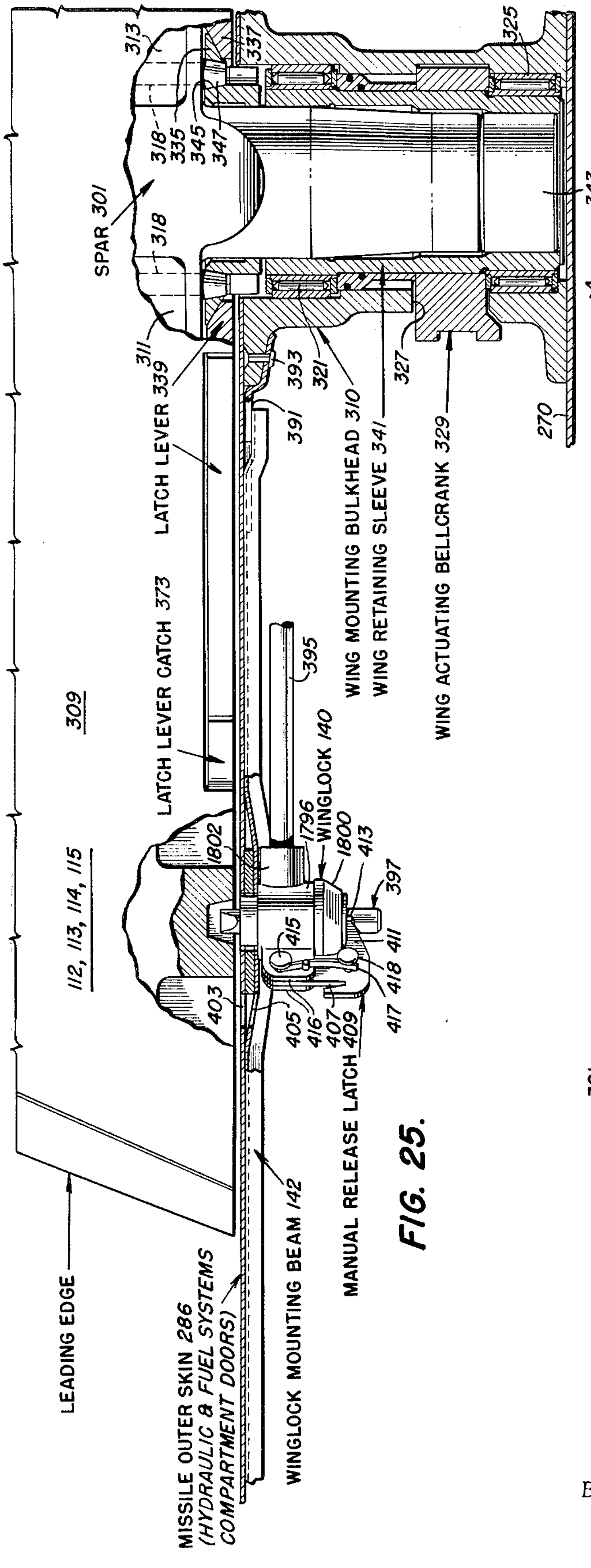

FIG. 25.

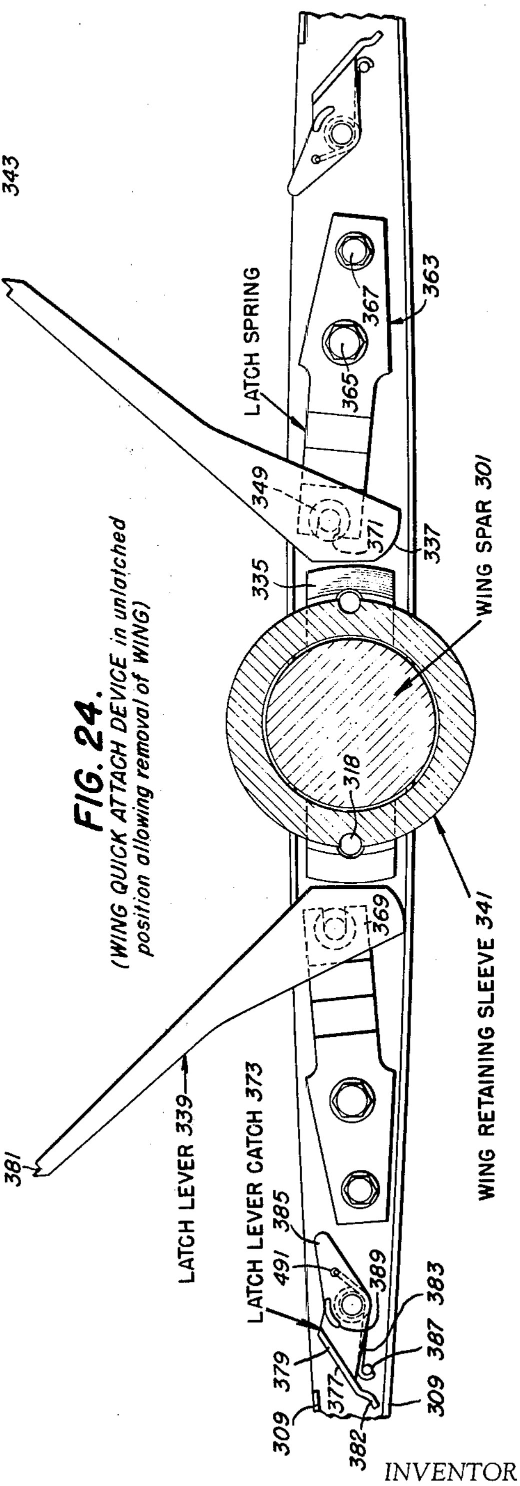

FIG. 24.
(WING QUICK ATTACH DEVICE in unlatched position allowing removal of WING)

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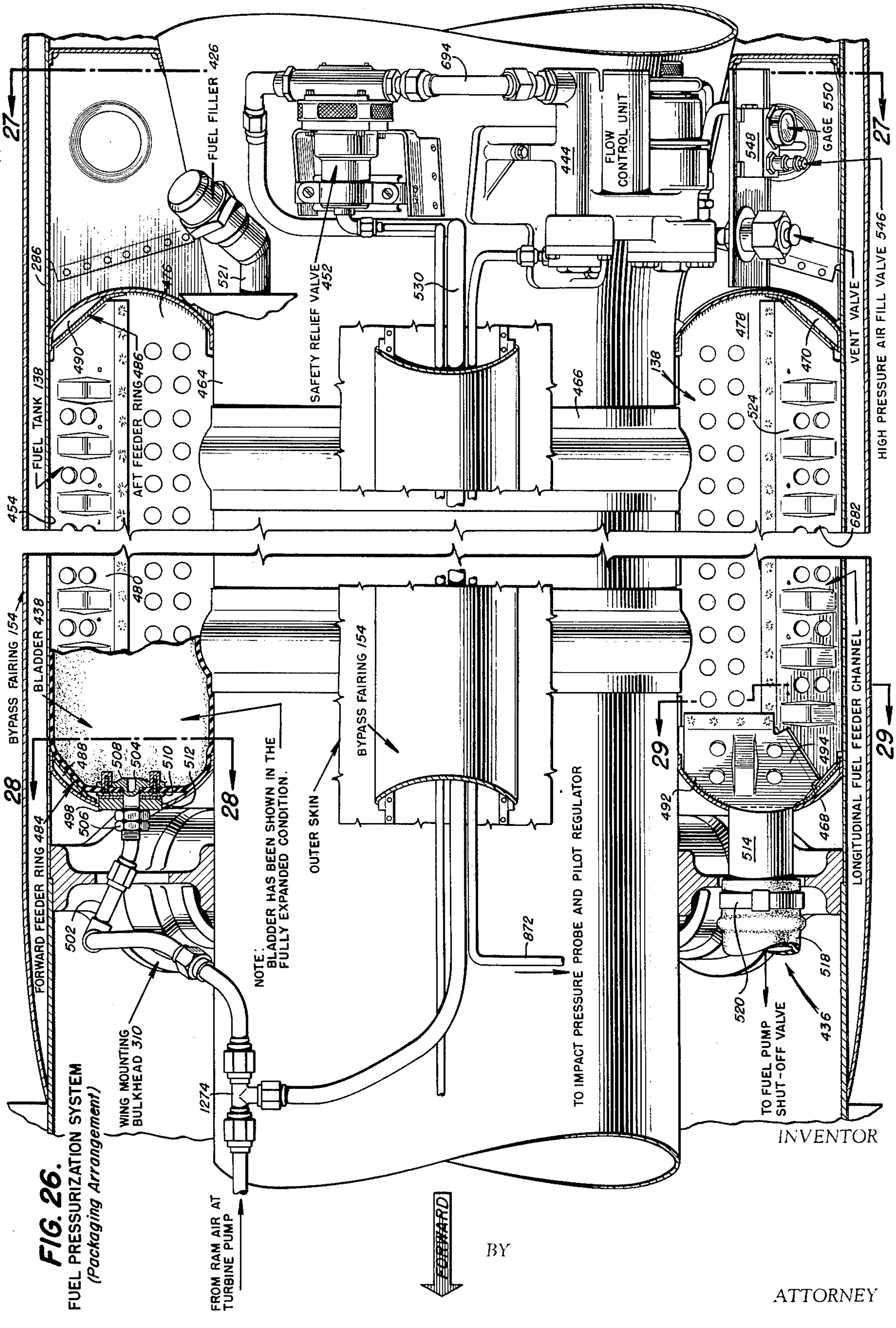

FIG. 26.
FUEL PRESSURIZATION SYSTEM
(Packaging Arrangement)

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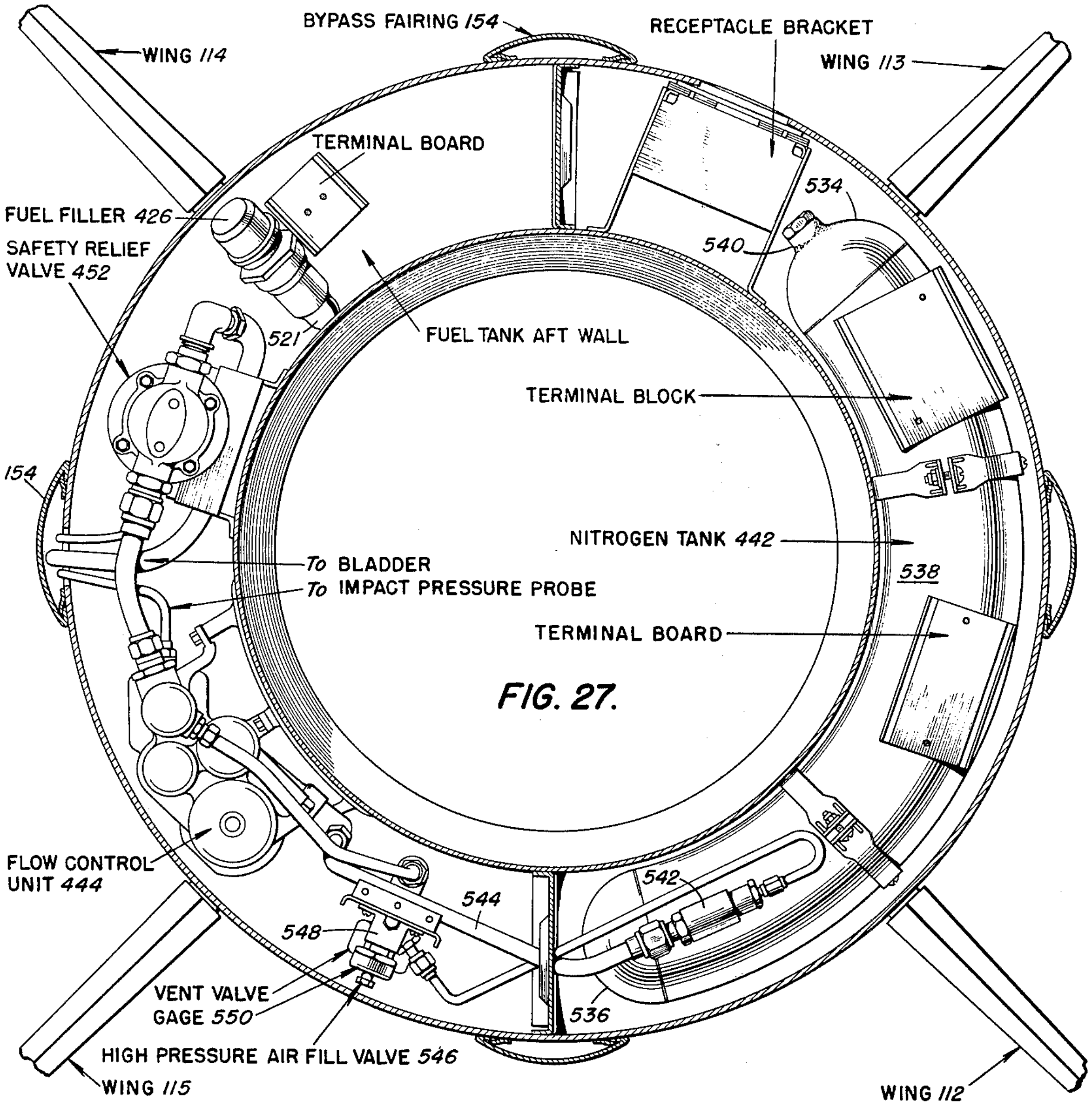

FIG. 27.

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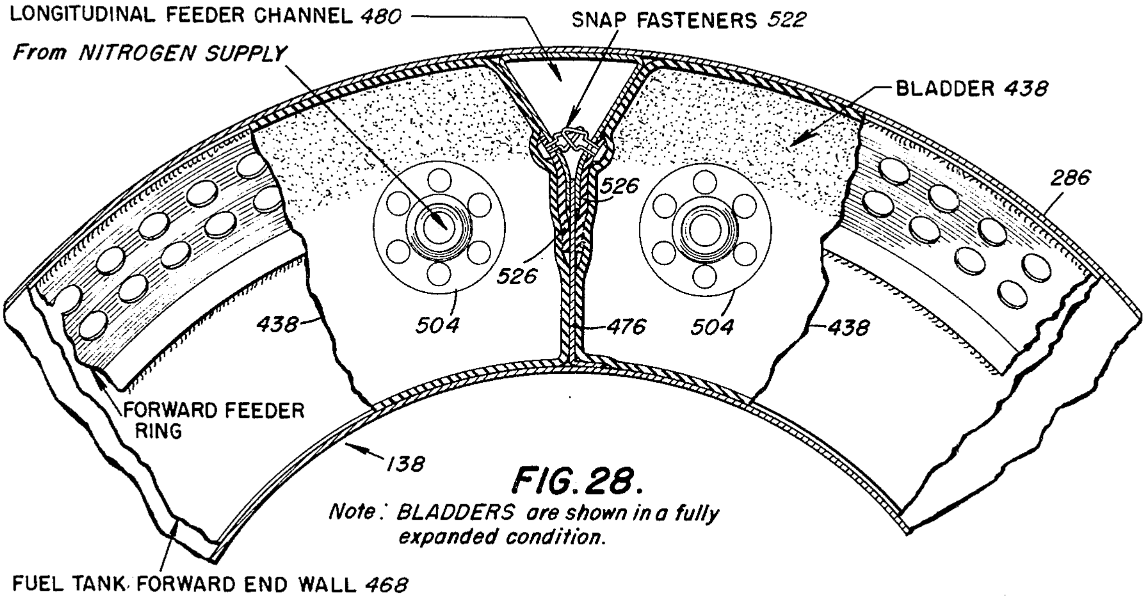

FIG. 28.

Note: BLADDERS are shown in a fully expanded condition.

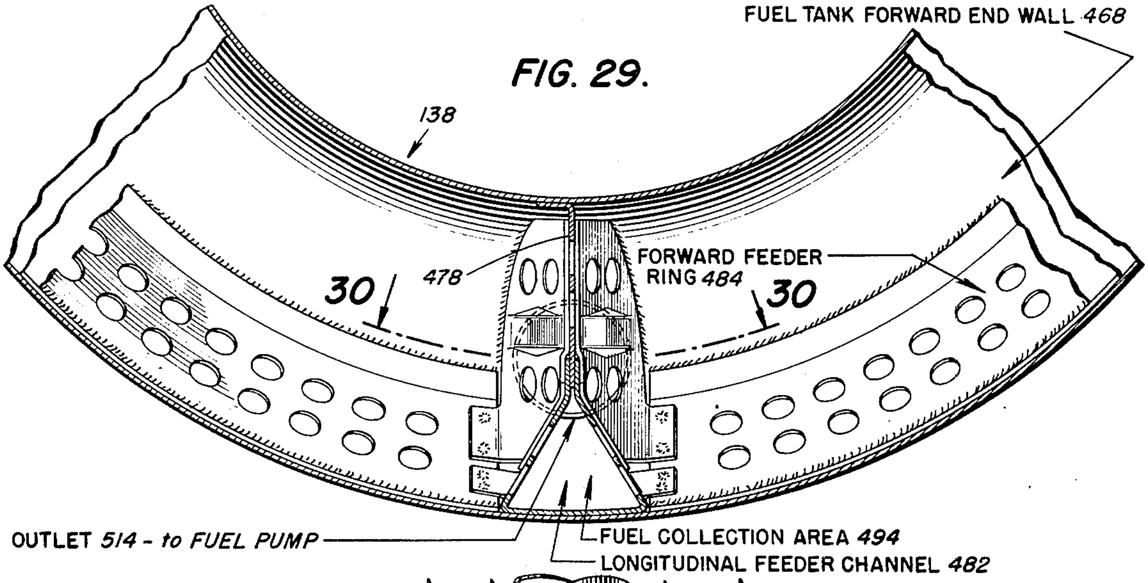

FIG. 29.

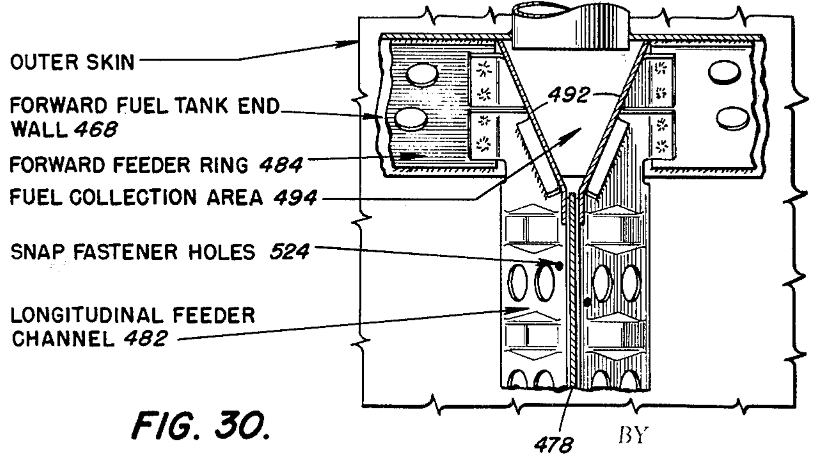

FIG. 30.

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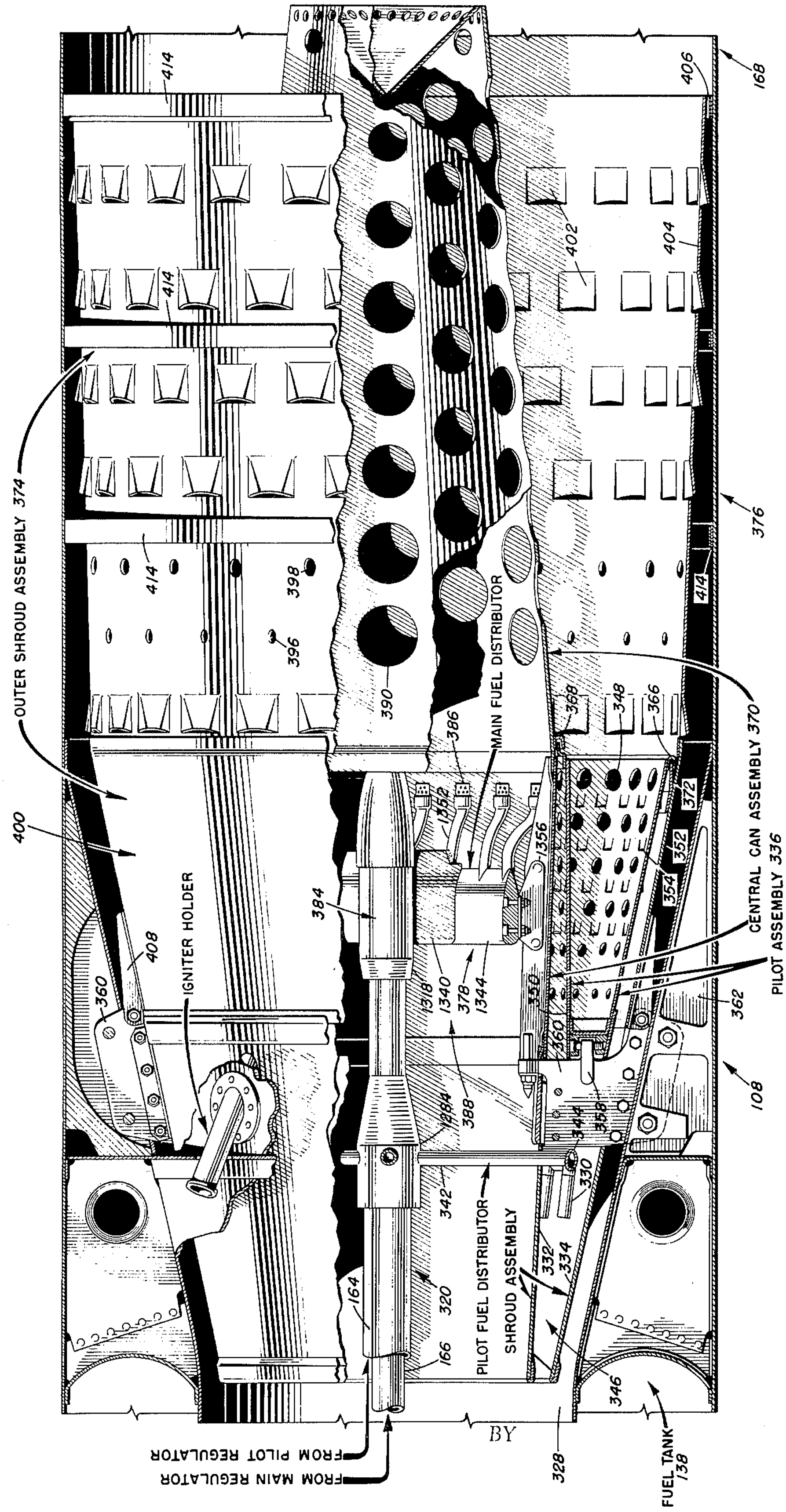

FIG. 31.
COMBUSTOR ASSEMBLY

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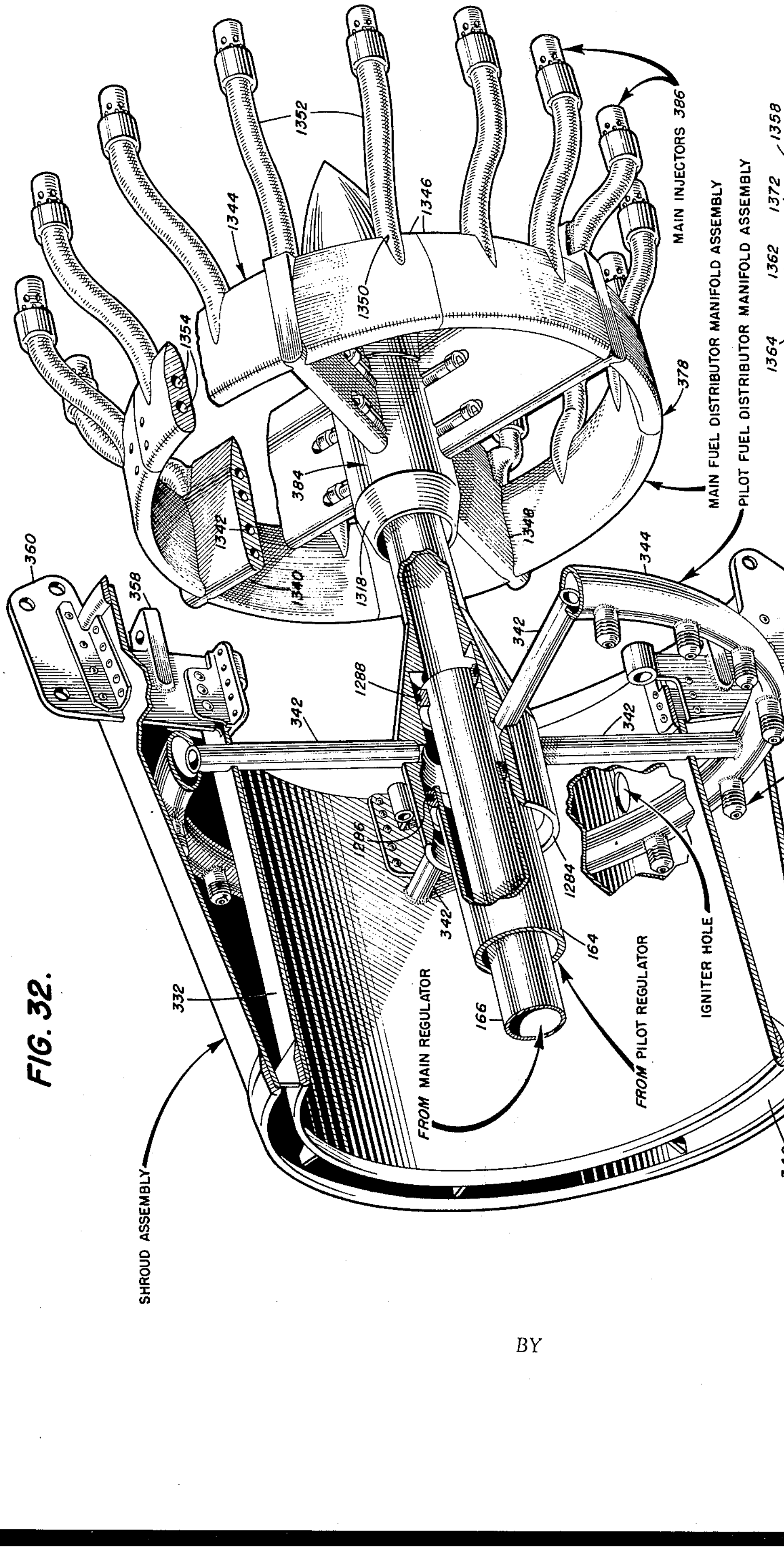
FIG. 32.

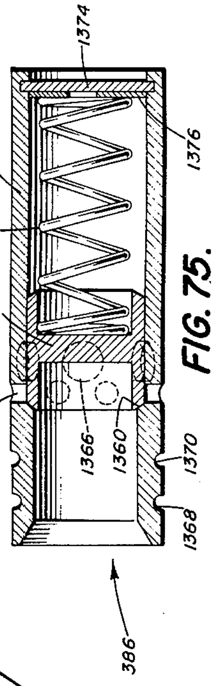
FIG. 75.

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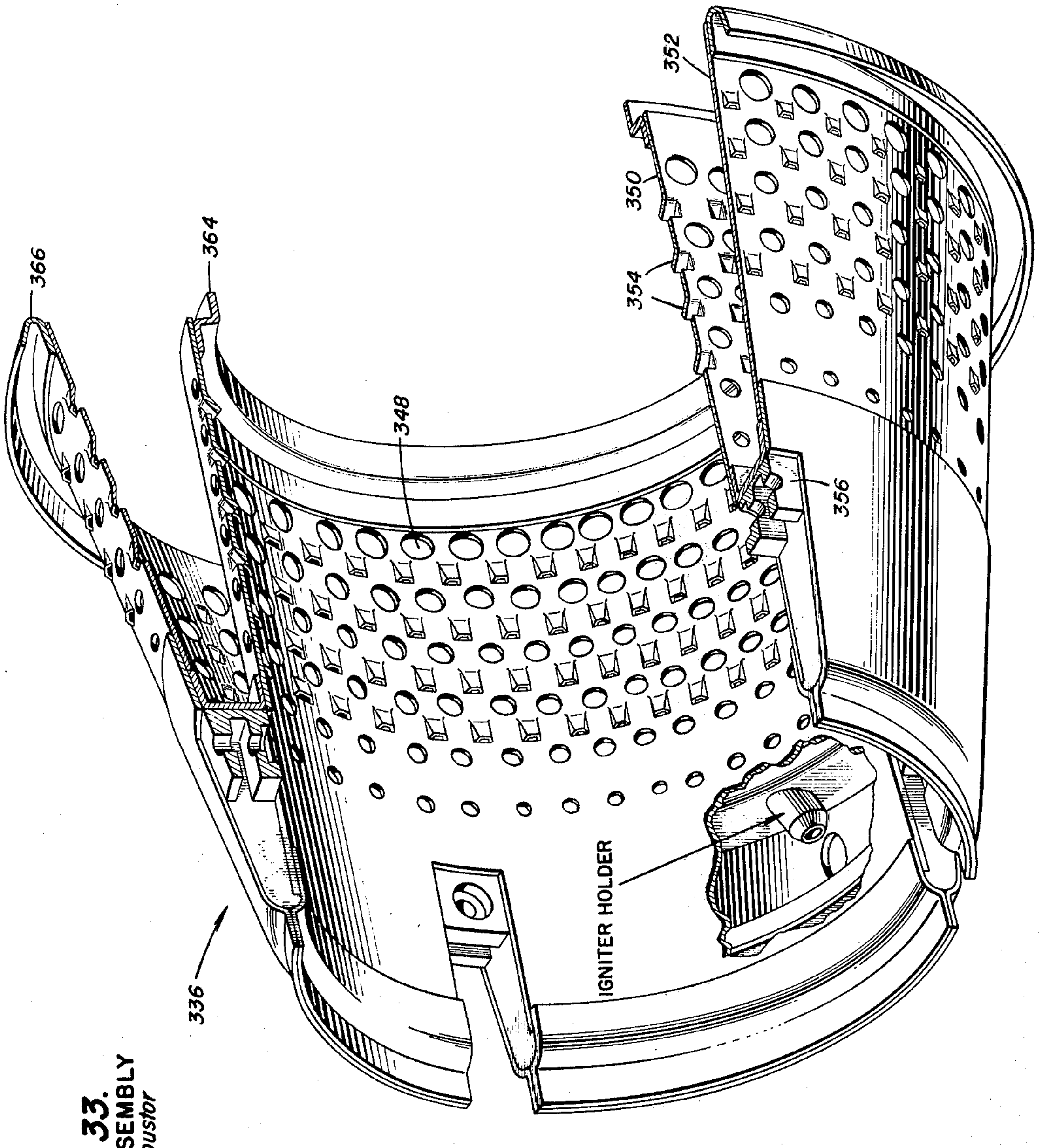

FIG. 33.
PILOT ASSEMBLY
Combustor

INVENTOR

BY

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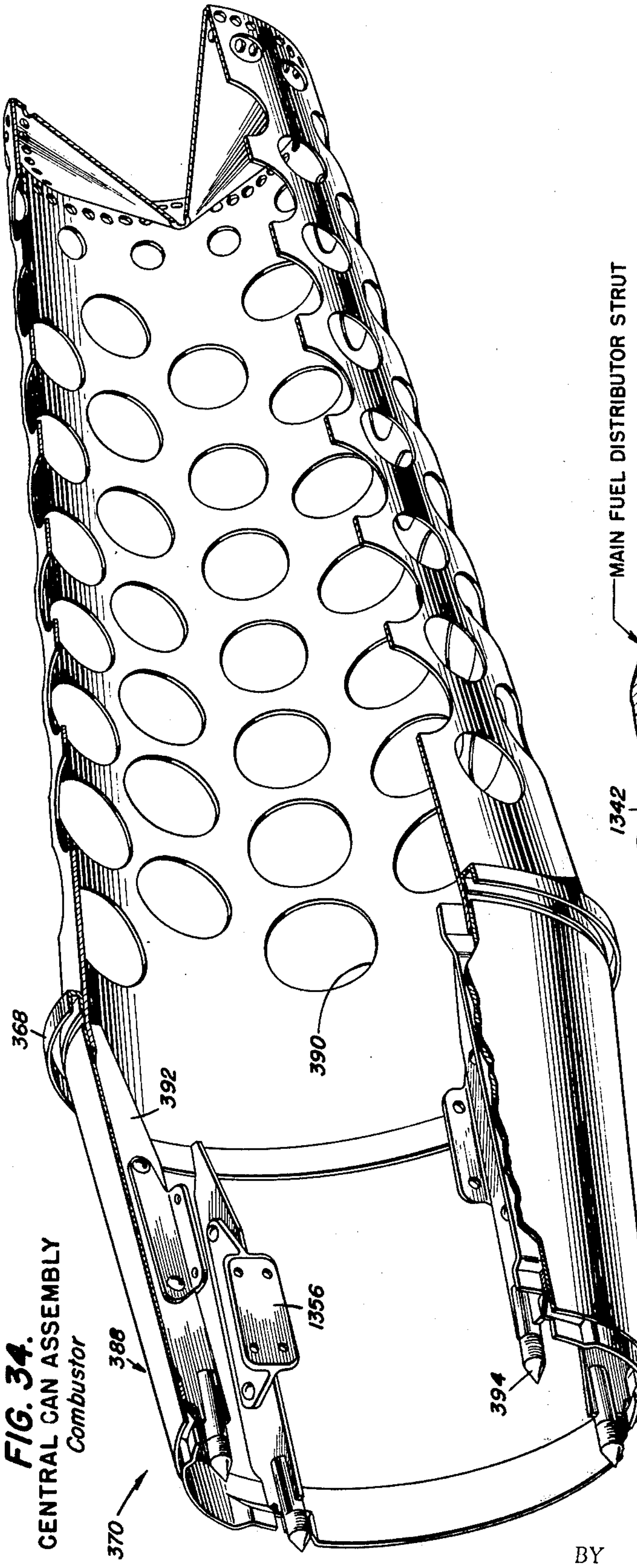

FIG. 34.
CENTRAL CAN ASSEMBLY
Combustor

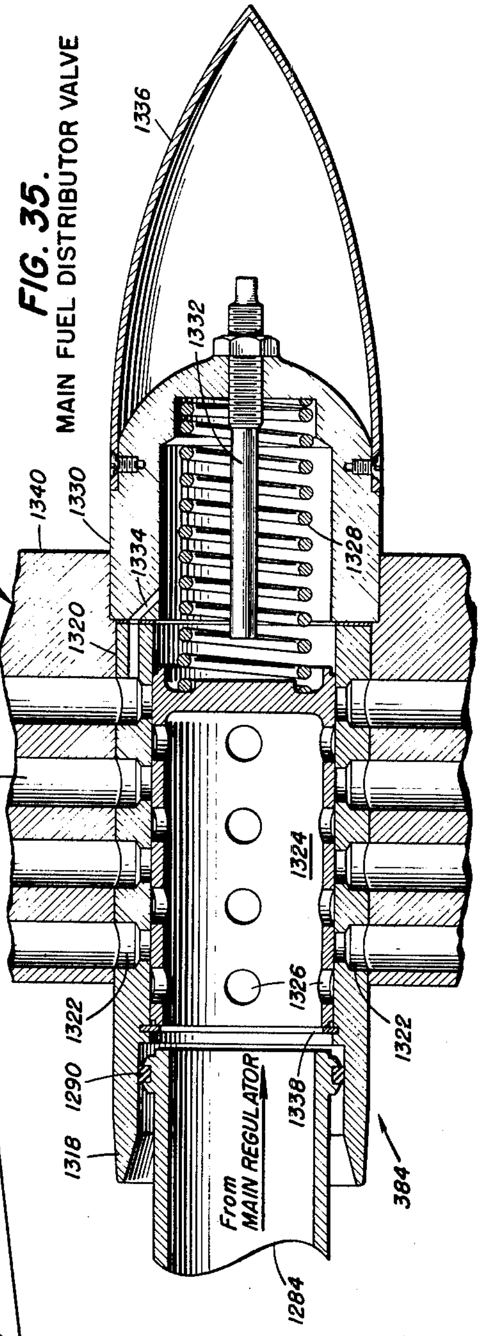

FIG. 35.
MAIN FUEL DISTRIBUTOR VALVE

INVENTOR

BY

ATTORNEY

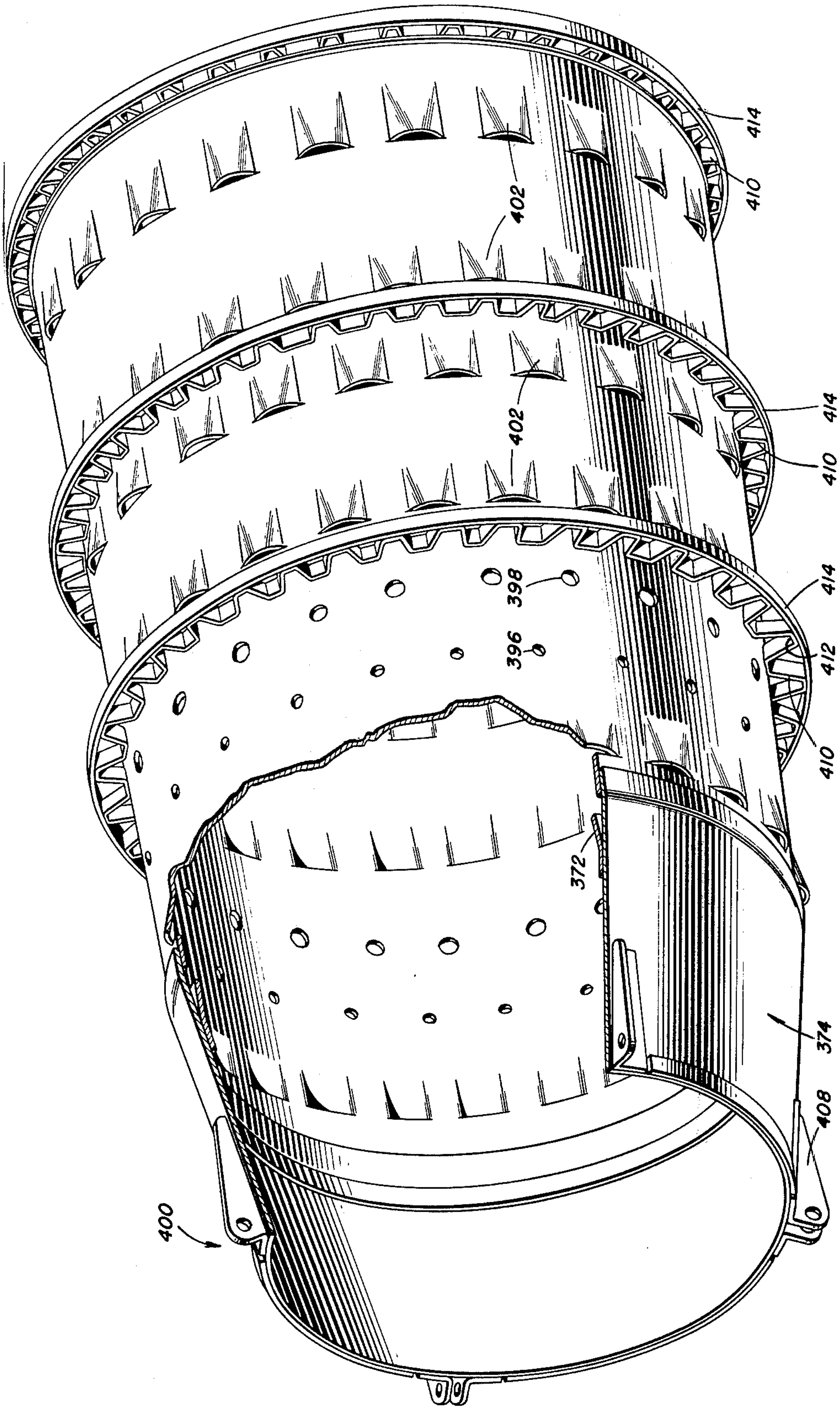

FIG. 36.
OUTER SHROUD ASSEMBLY
Combustor

INVENTOR

BY

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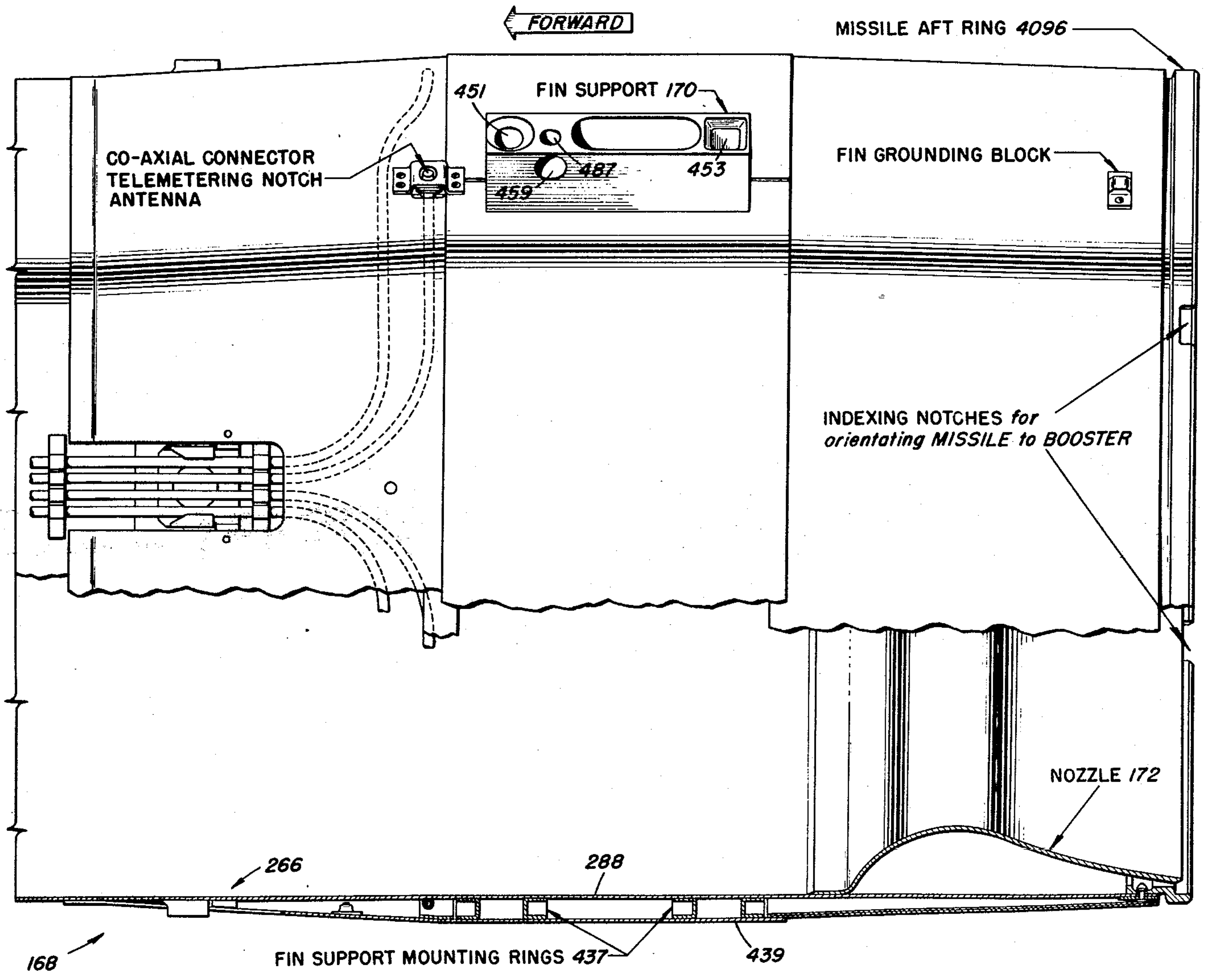
FIG. 37.
TAILPIPE ASSEMBLY

NOTE:
In order to more clearly illustrate the CO-AXIAL CONNECTORS to the TELEMETERING NOTCH ANTENNA, this view has been rotated 180° about the missile axis, from the normal position.



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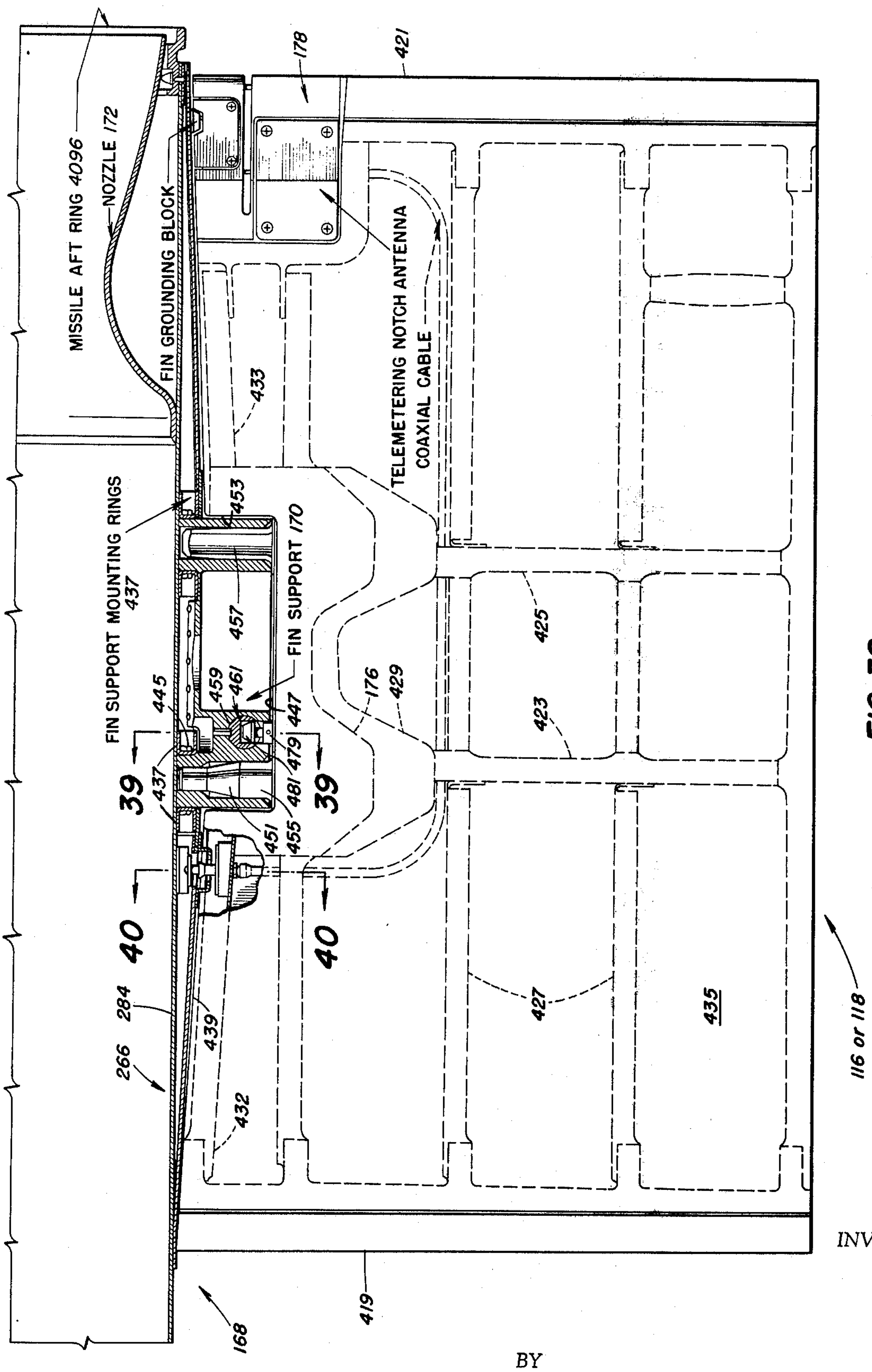

FIG. 38.
FIN ASSEMBLY AND ATTACHING MEANS

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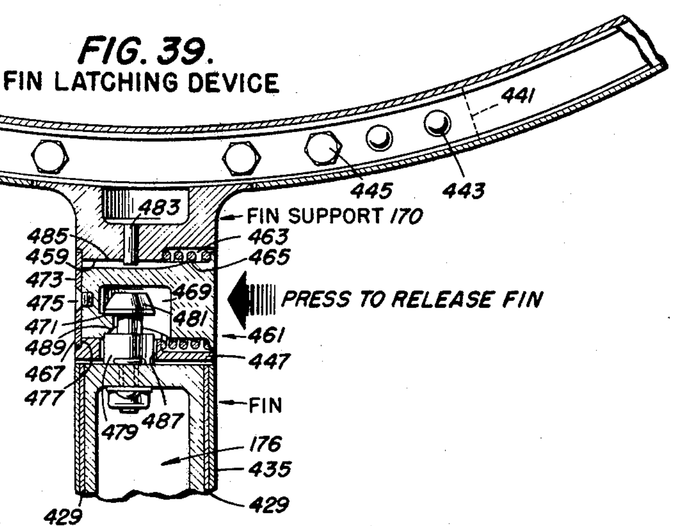

FIG. 39.
FIN LATCHING DEVICE

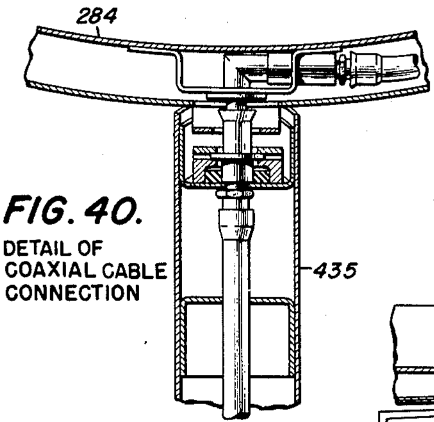

FIG. 40.
DETAIL OF
COAXIAL CABLE
CONNECTION

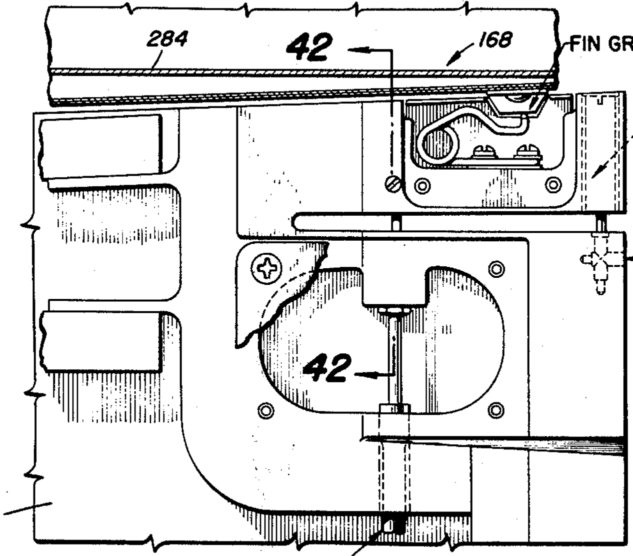

FIG. 41.
TELEMETERING NOTCH ANTENNA

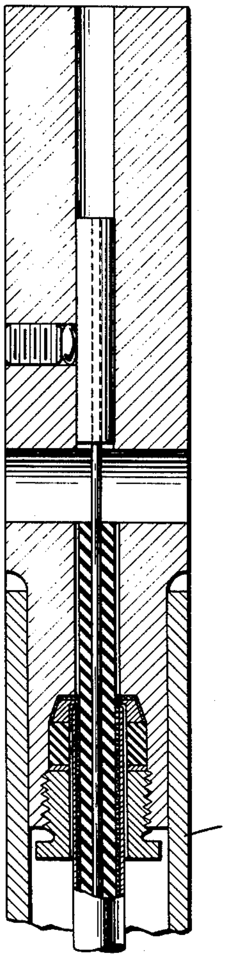

FIG. 42.

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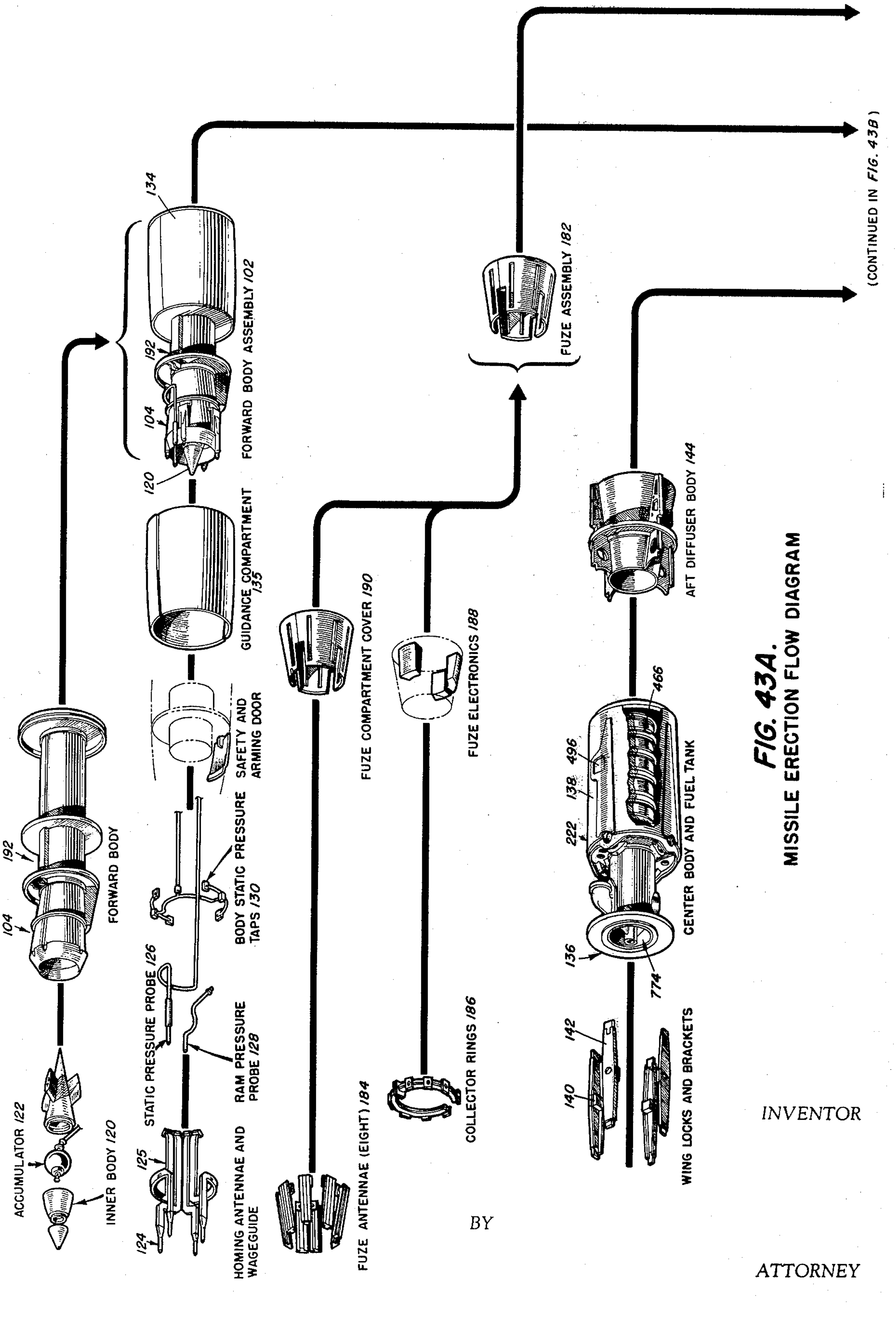

FIG. 43A.
MISSILE ERECTION FLOW DIAGRAM

INVENTOR

BY

ATTORNEY

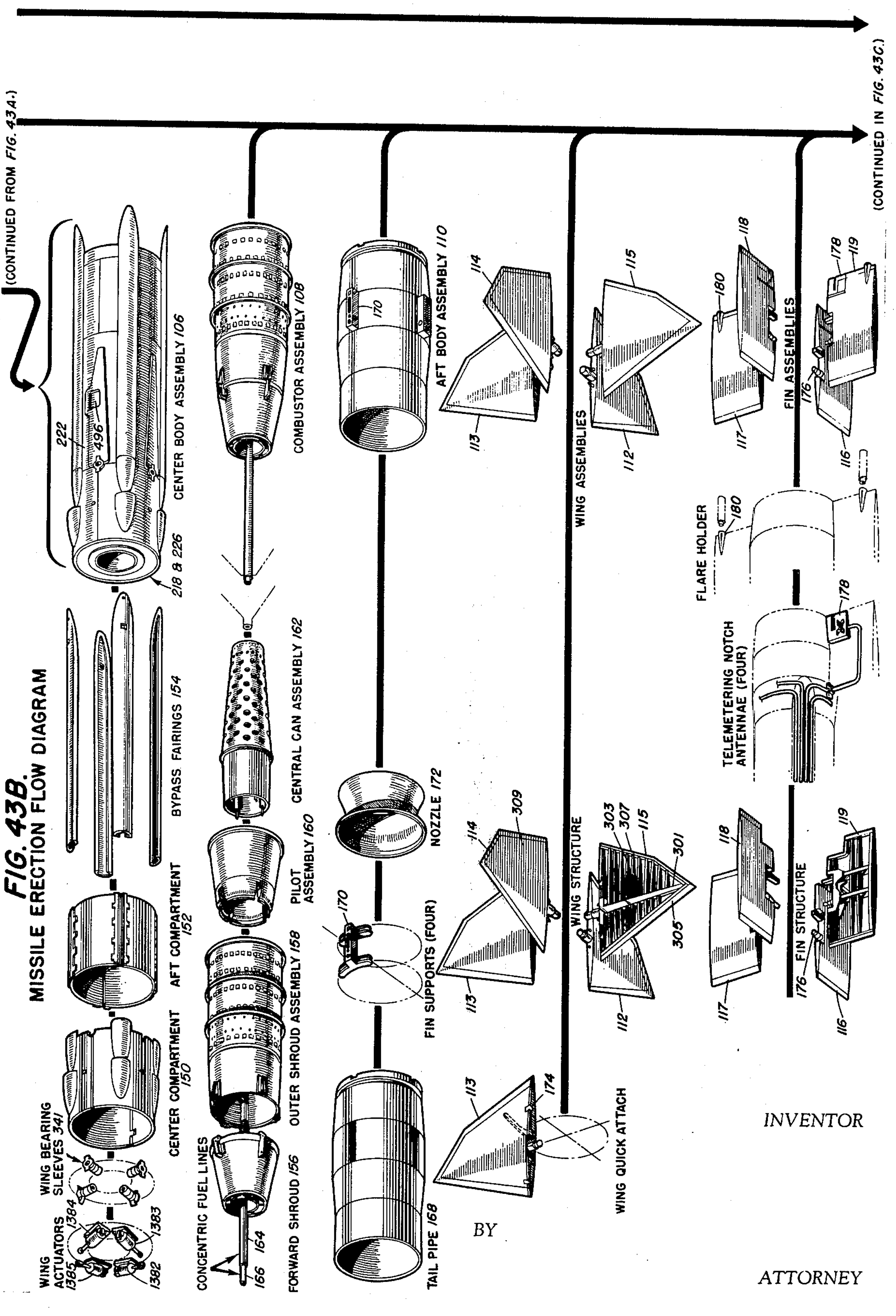

FIG. 43B.
MISSILE ERECTION FLOW DIAGRAM

INVENTOR

BY

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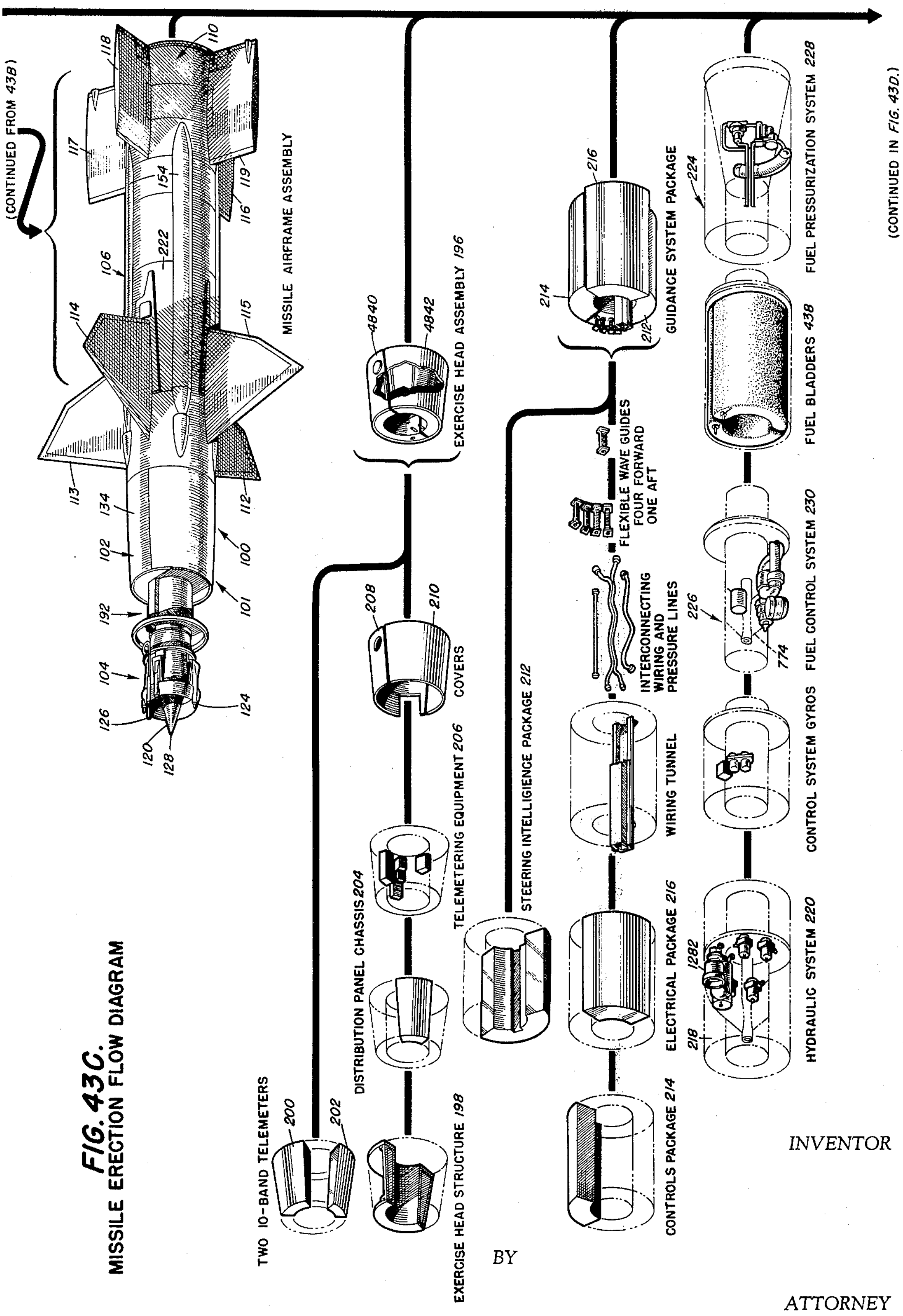

FIG. 43C.
MISSILE ERECTION FLOW DIAGRAM

INVENTOR

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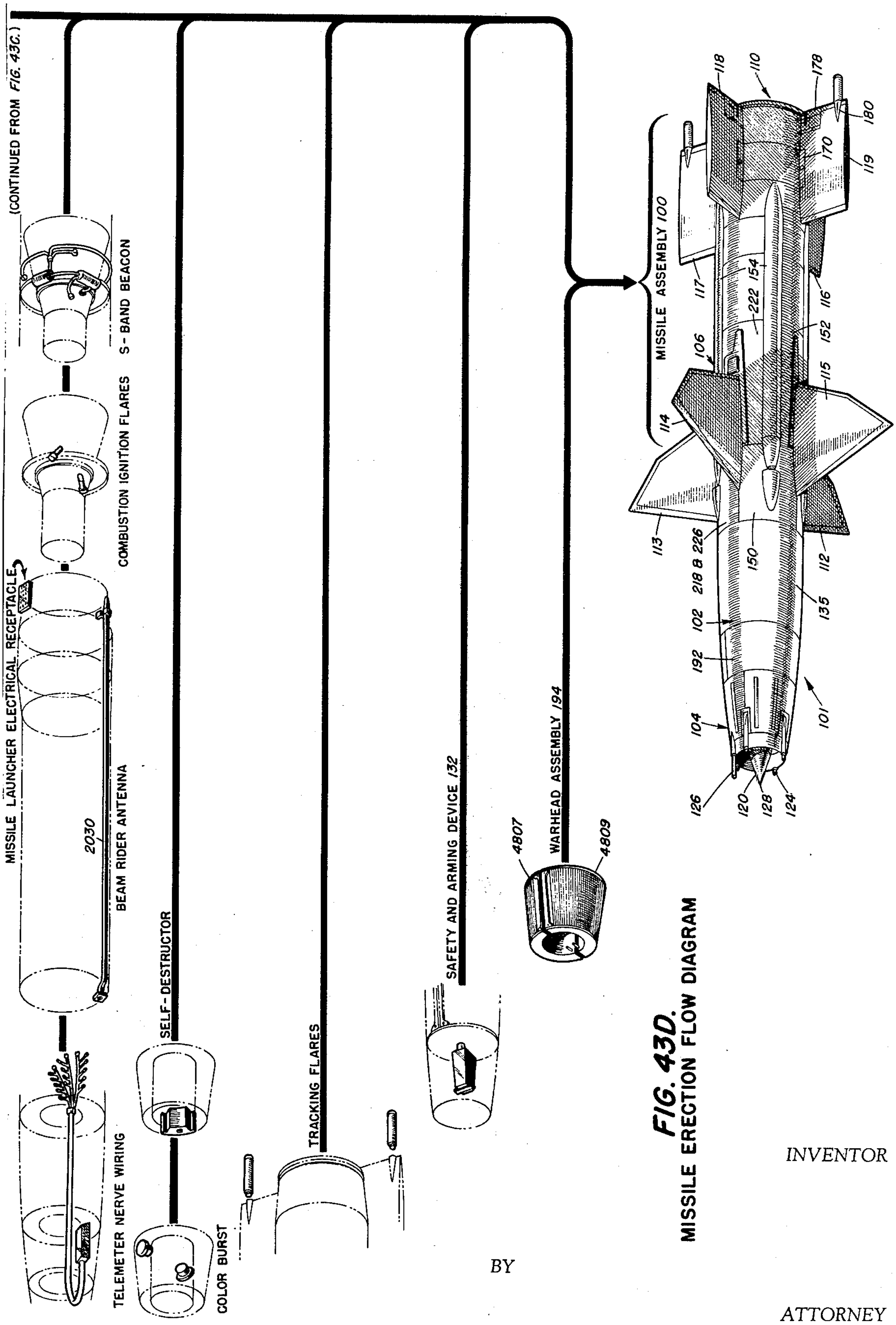

FIG. 43D.
MISSILE ERECTION FLOW DIAGRAM

INVENTOR

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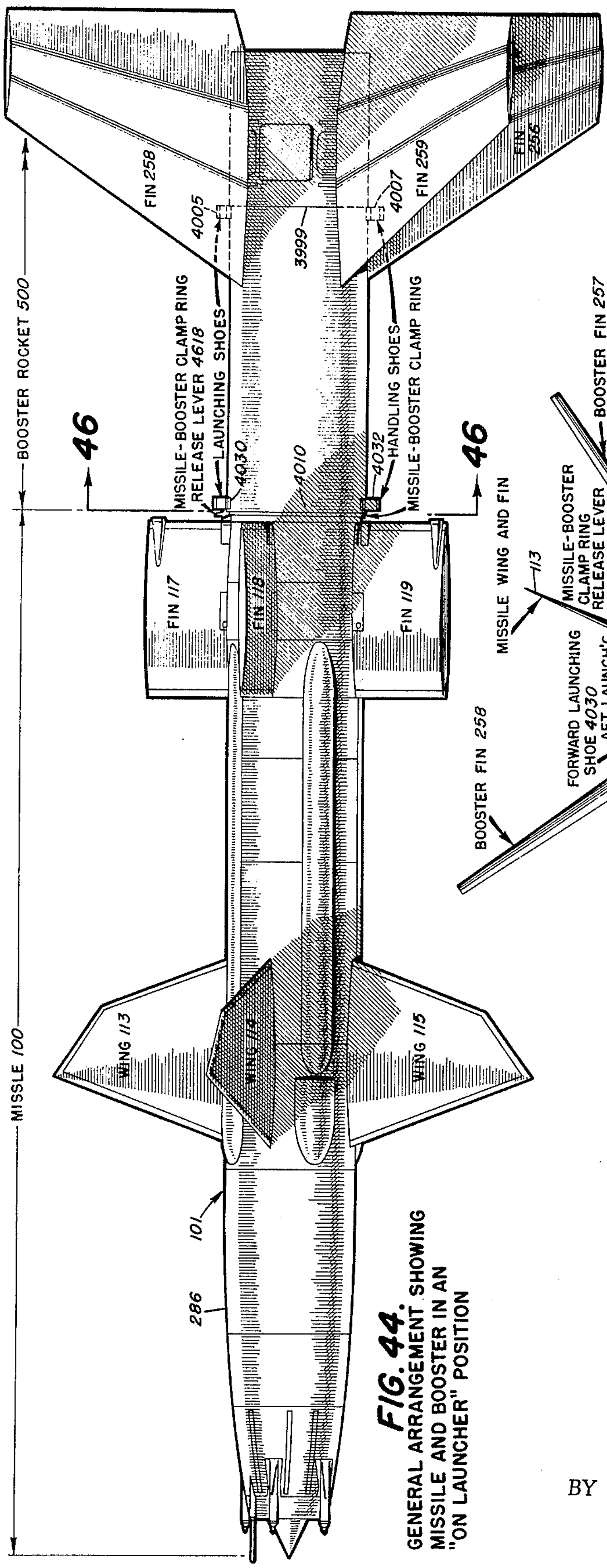

FIG. 44.
GENERAL ARRANGEMENT SHOWING MISSILE AND BOOSTER IN AN "ON LAUNCHER" POSITION

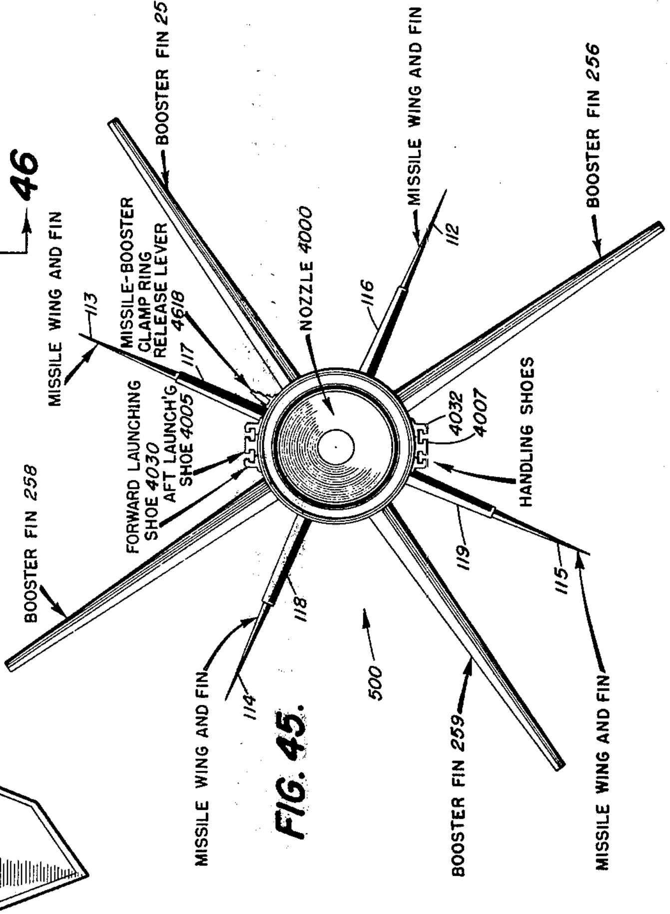

FIG. 45.

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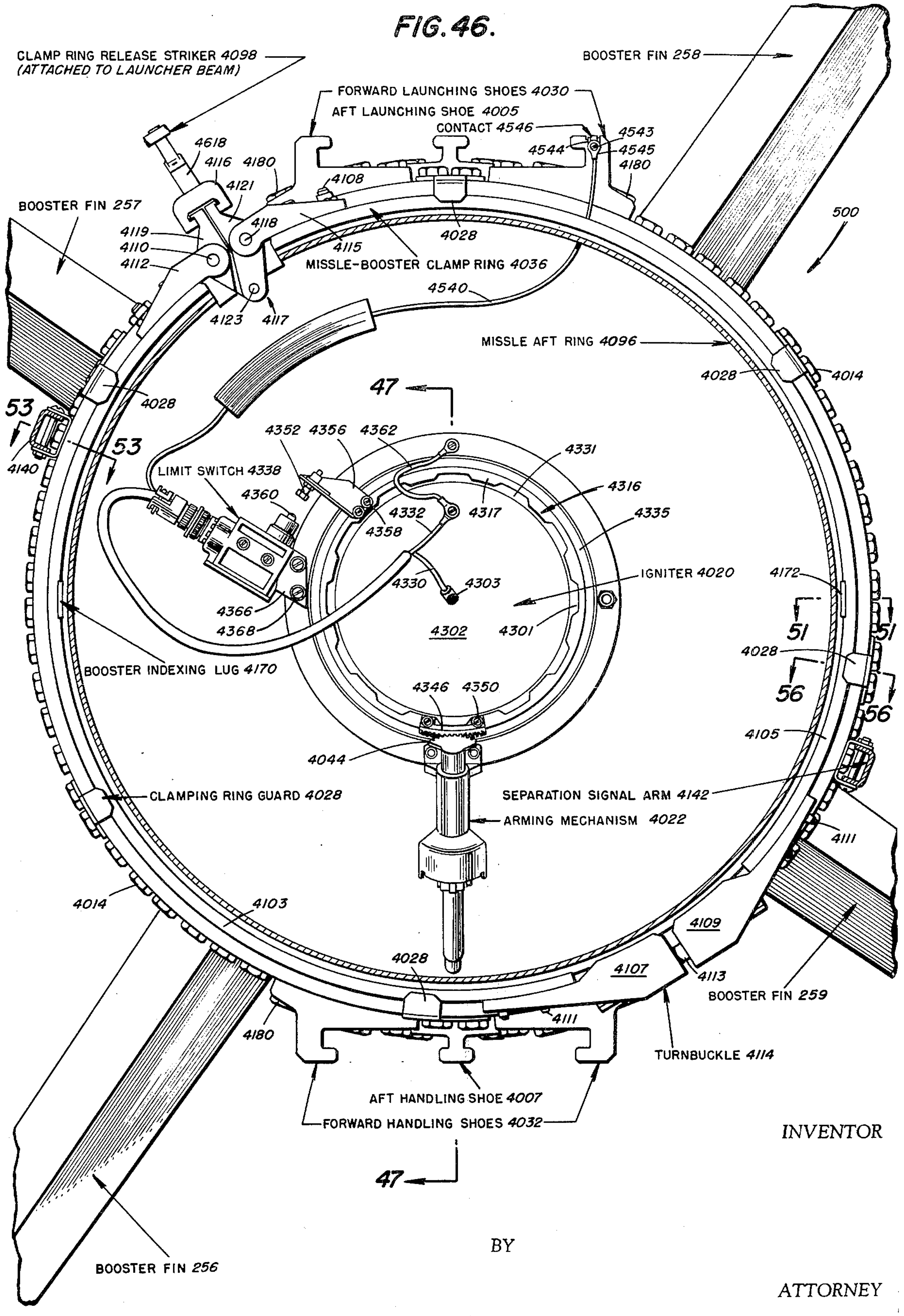
FIG. 46.



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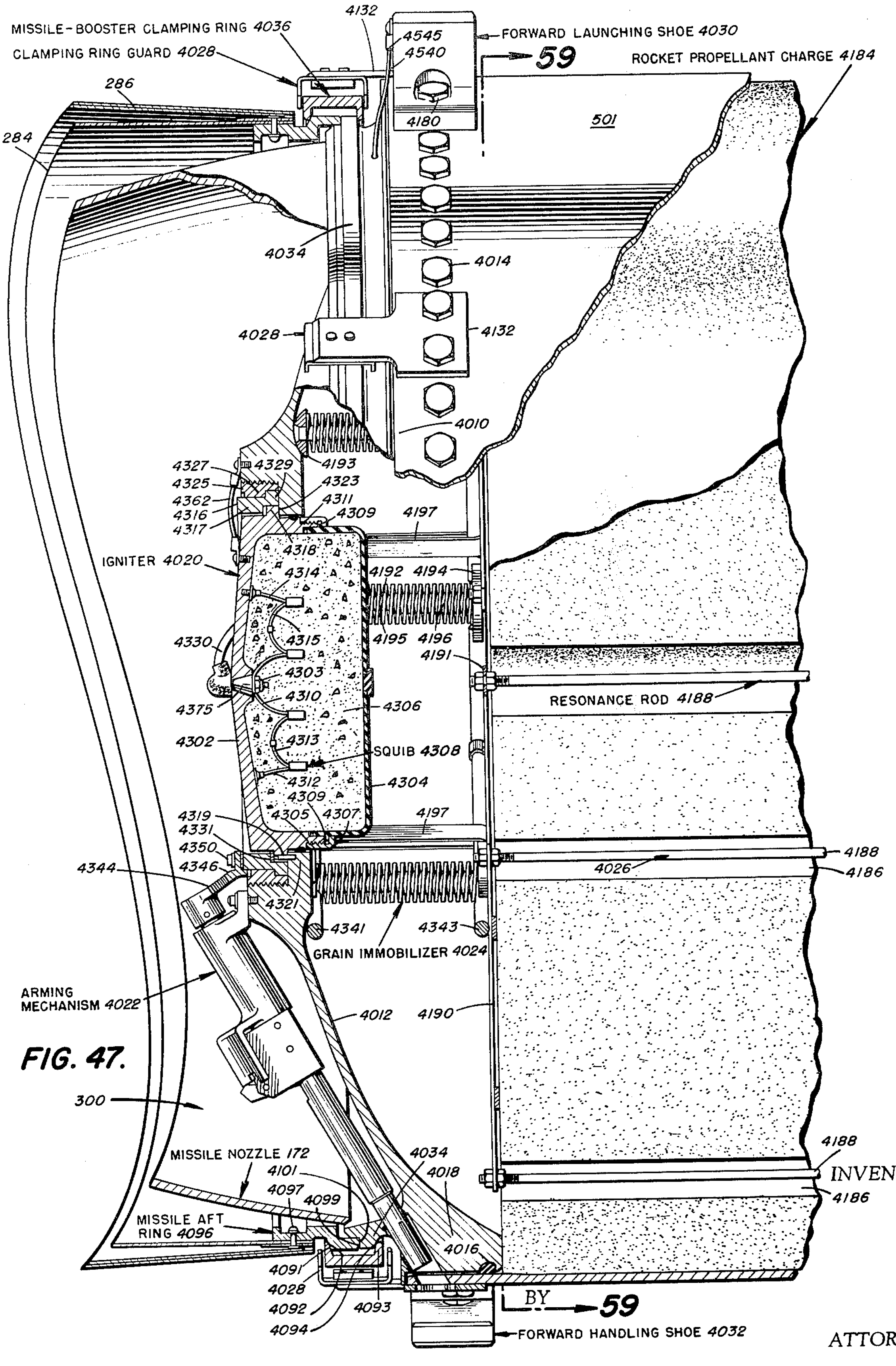

FIG. 47.

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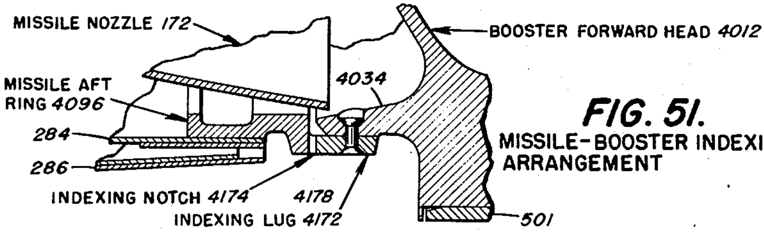

FIG. 51.
MISSILE-BOOSTER INDEXING ARRANGEMENT

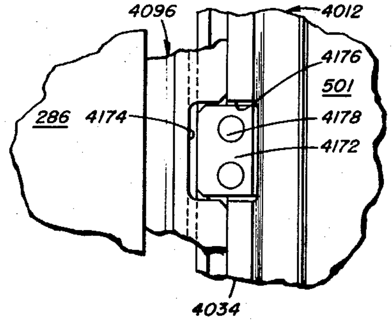

FIG. 52.

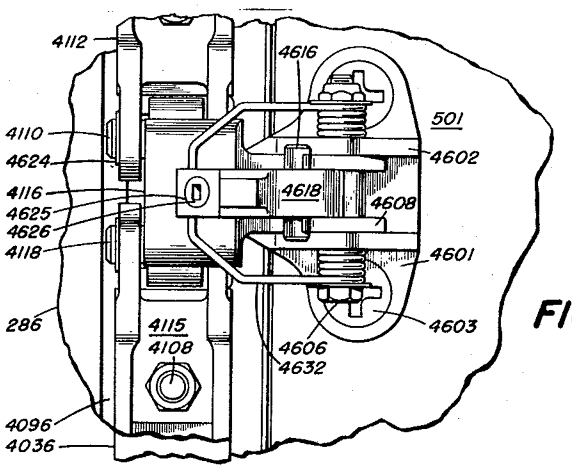

FIG. 50.

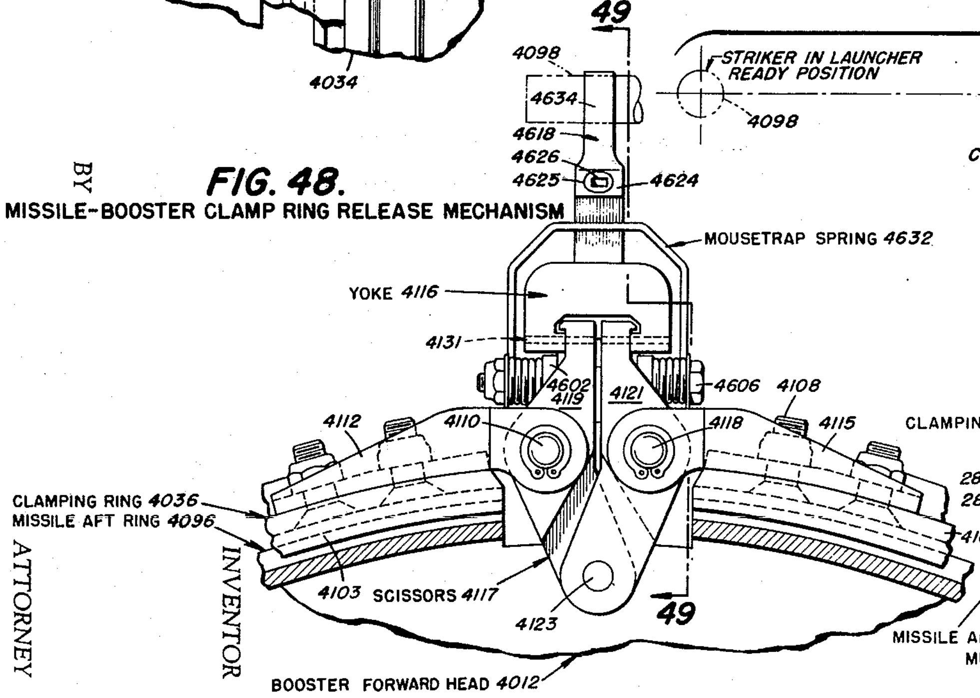

FIG. 48.
MISSILE-BOOSTER CLAMP RING RELEASE MECHANISM

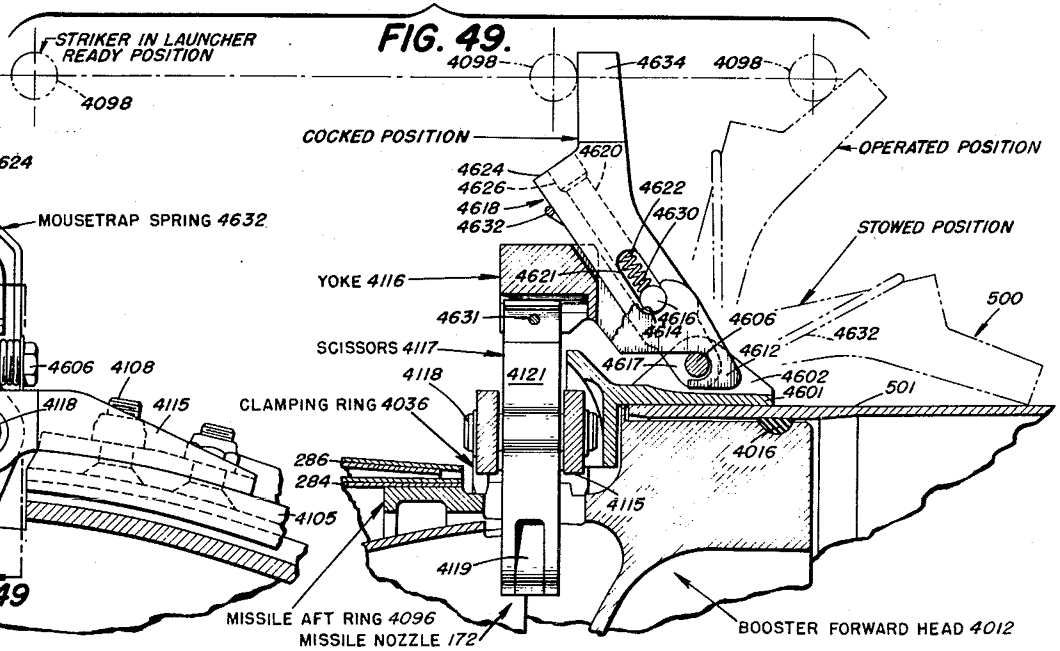

FIG. 49.

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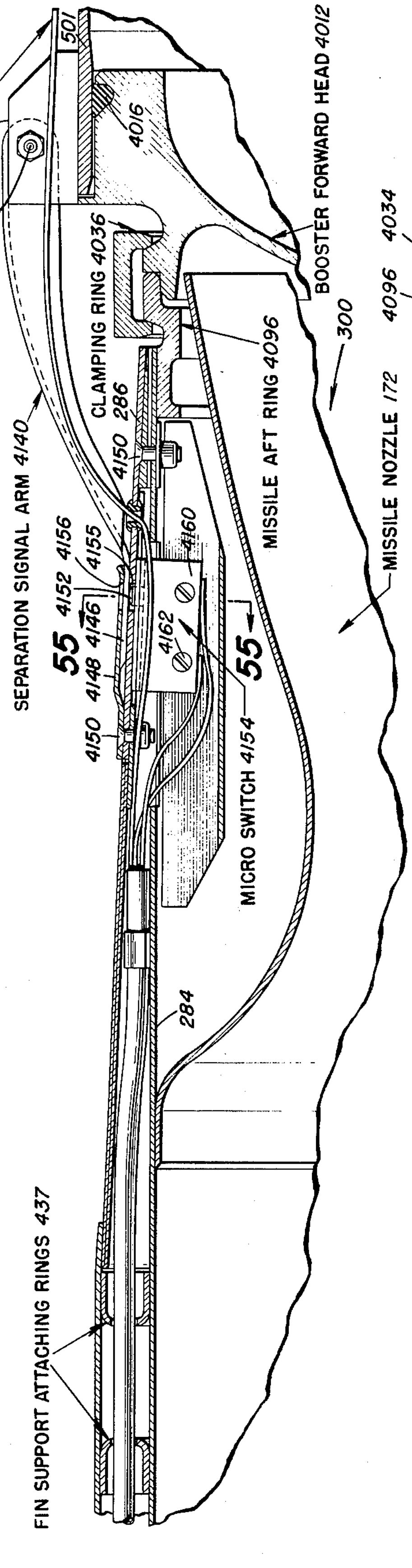
ATTORNEY

FIG. 53.
SEPARATION SIGNAL ARRANGEMENT



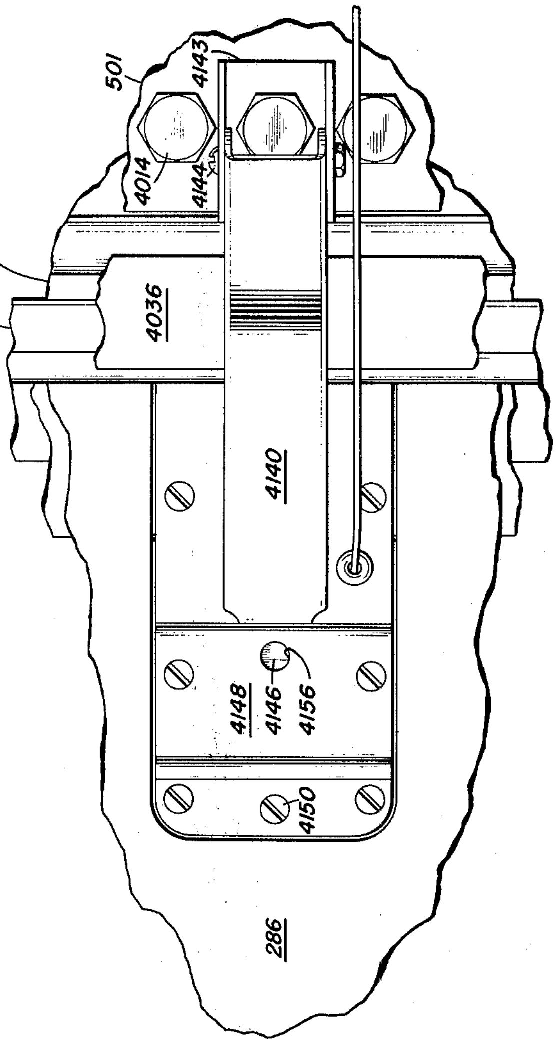


FIG. 54.

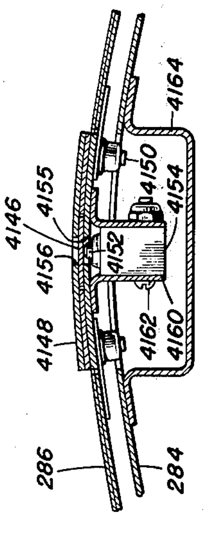


FIG. 55.

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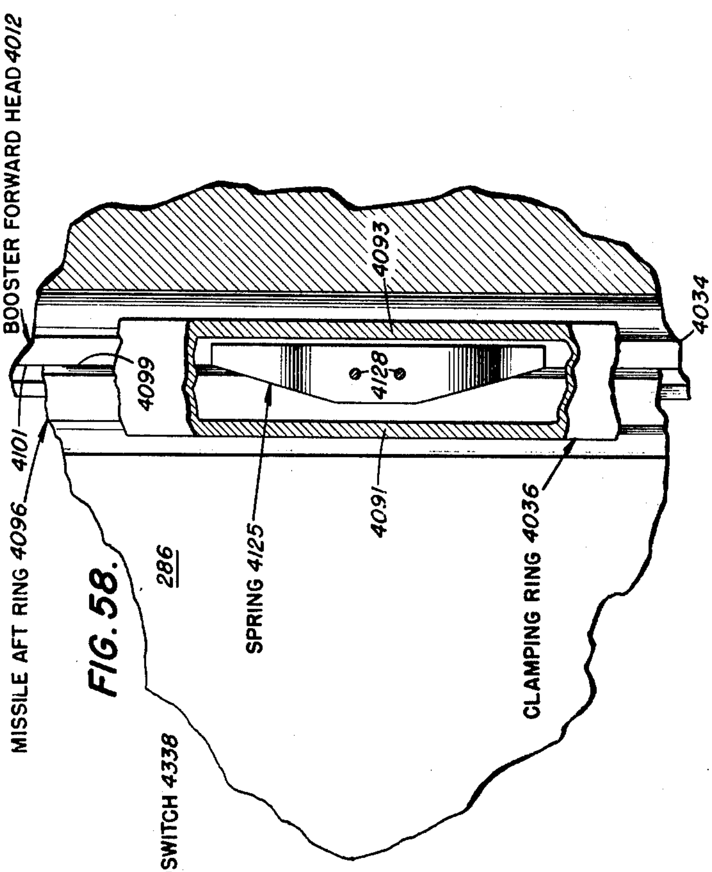
FIG. 58.

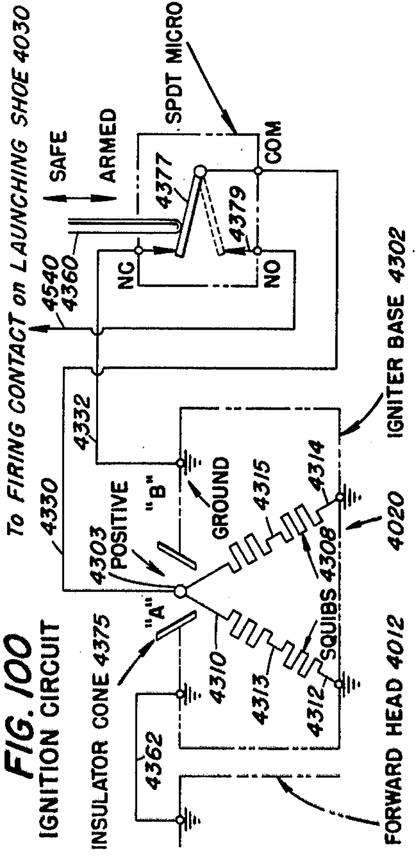
FIG. 100
IGNITION CIRCUIT

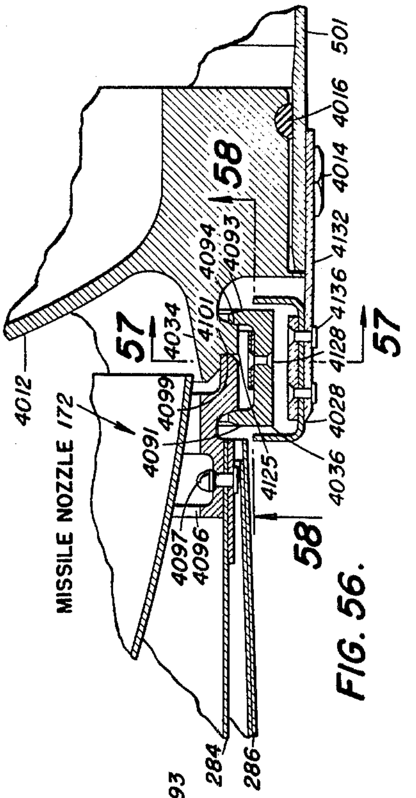
FIG. 56.

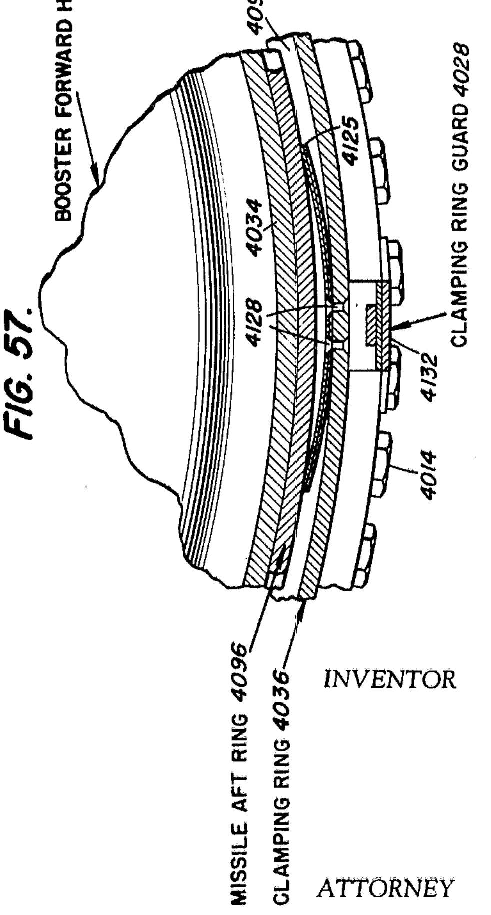
FIG. 57.

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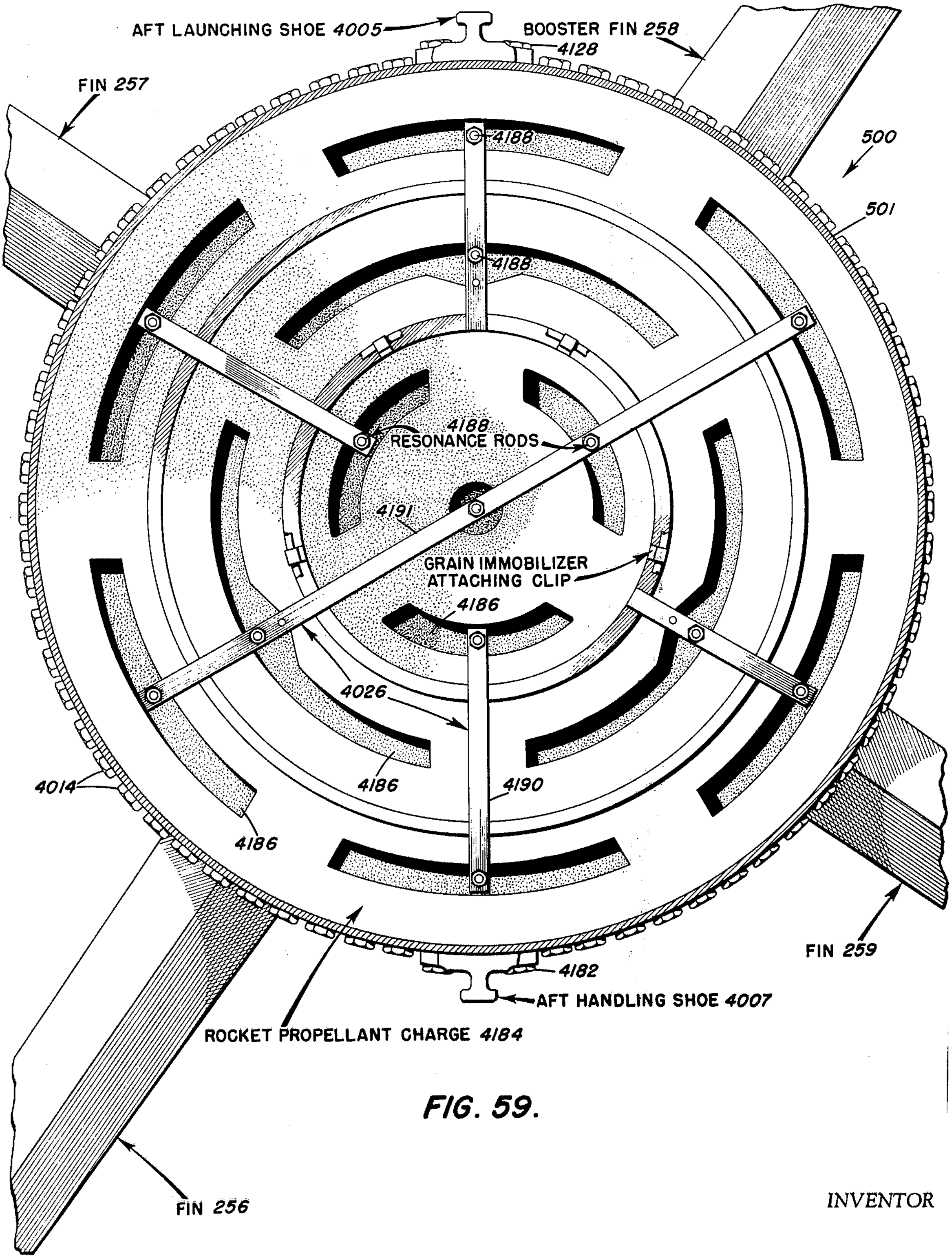

FIG. 59.

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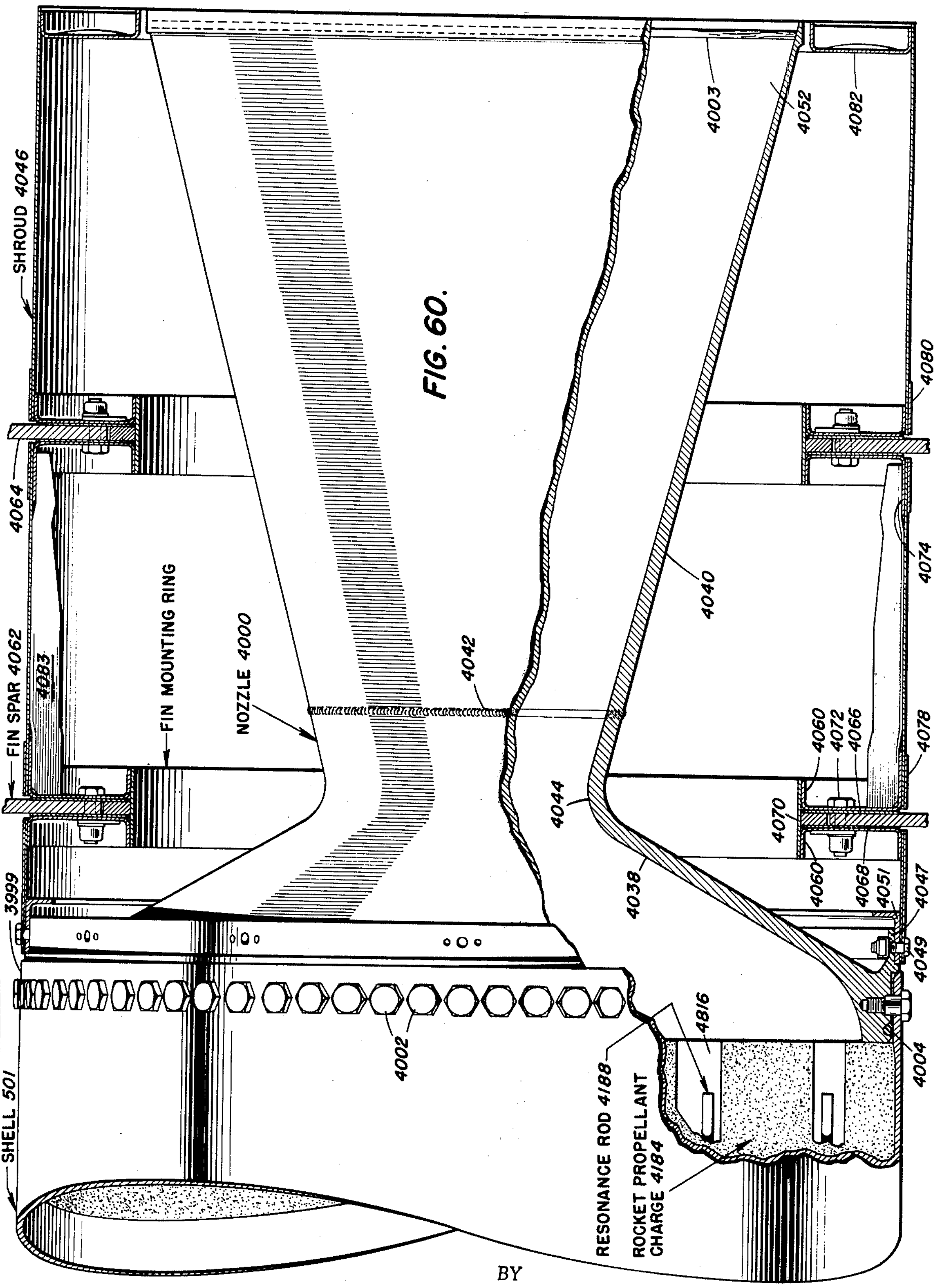

FIG. 60.

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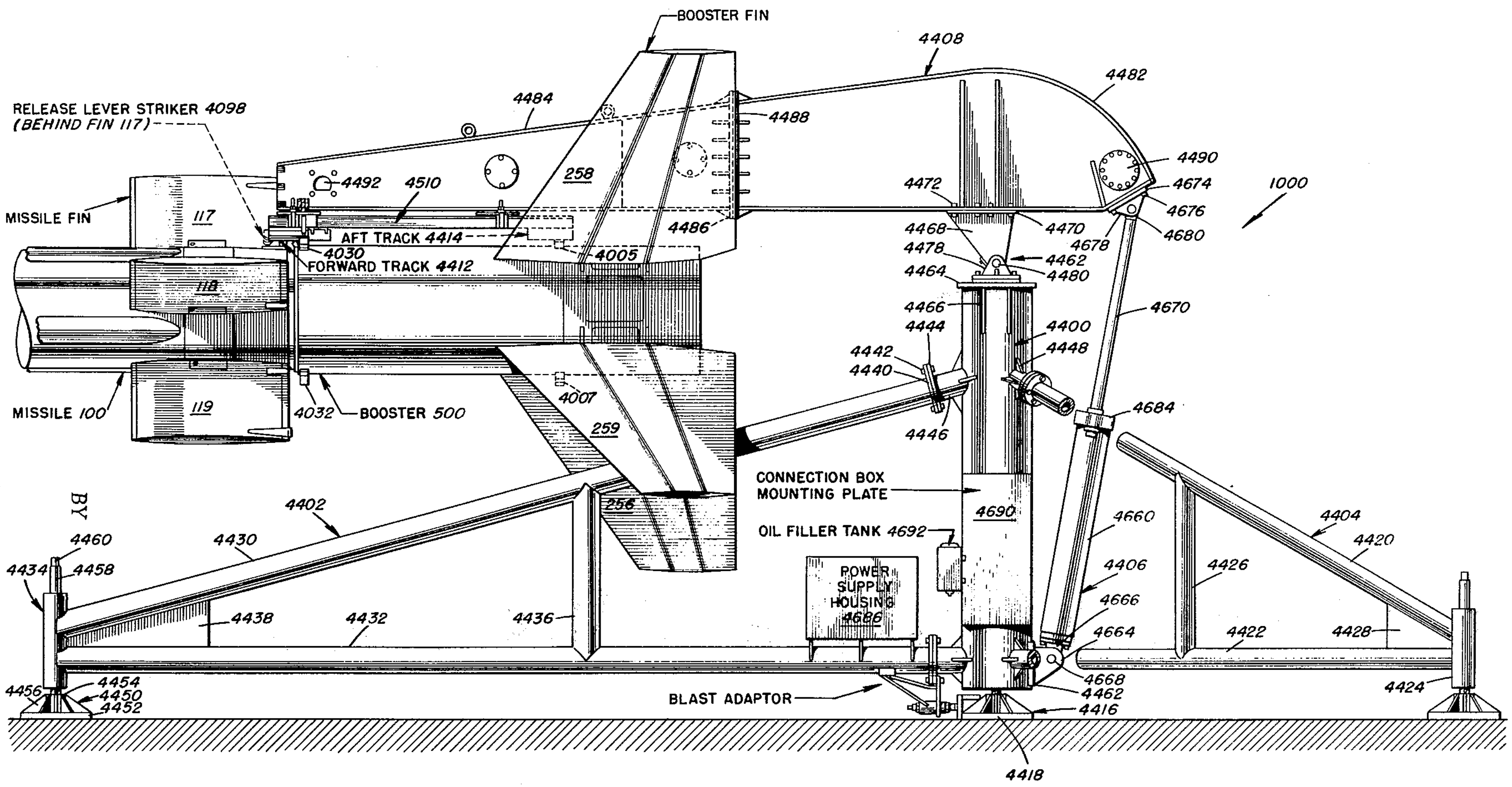

FIG. 61.
LAUNCHER
General Arrangement

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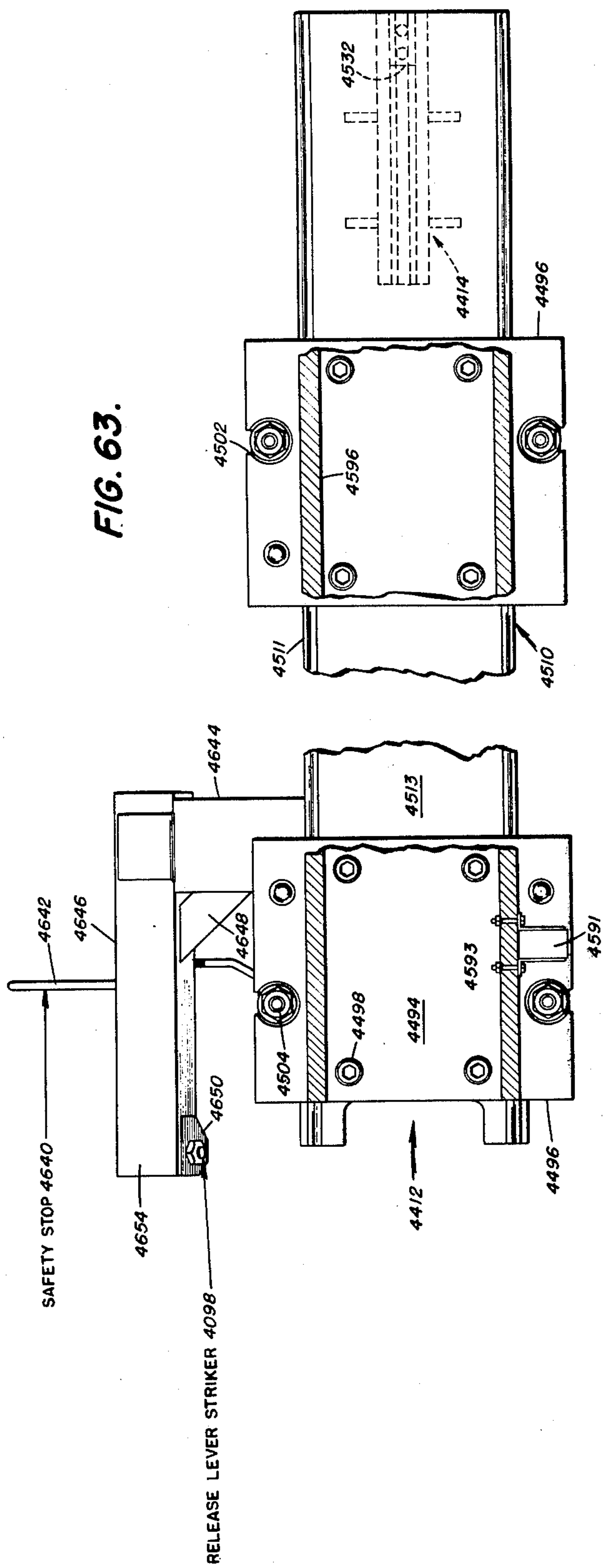

FIG. 63.

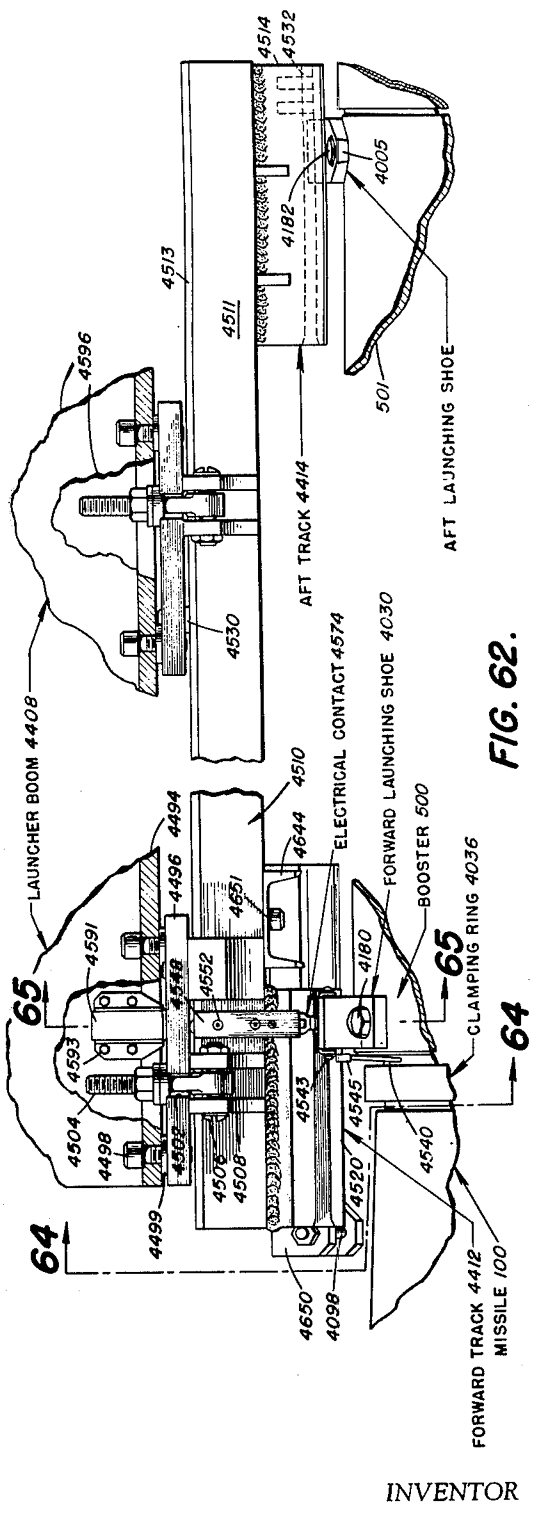

FIG. 62.

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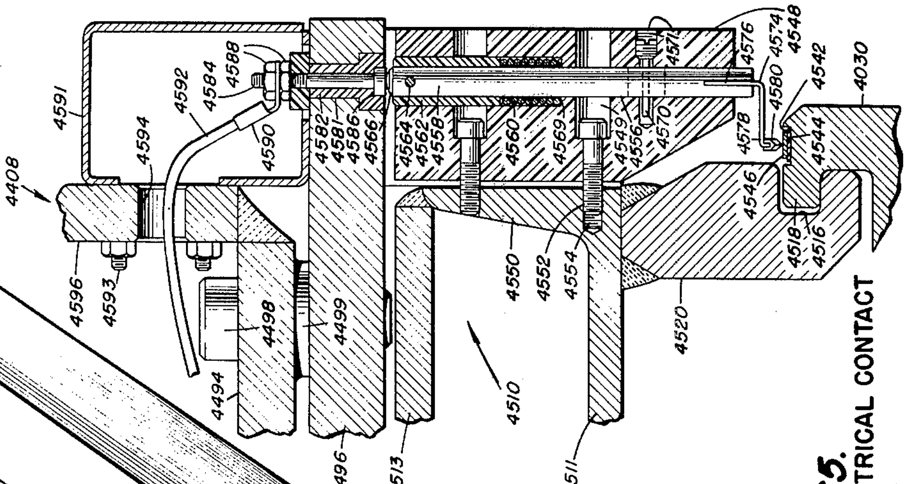

FIG. 65.
BOOSTER IGNITER ELECTRICAL CONTACT

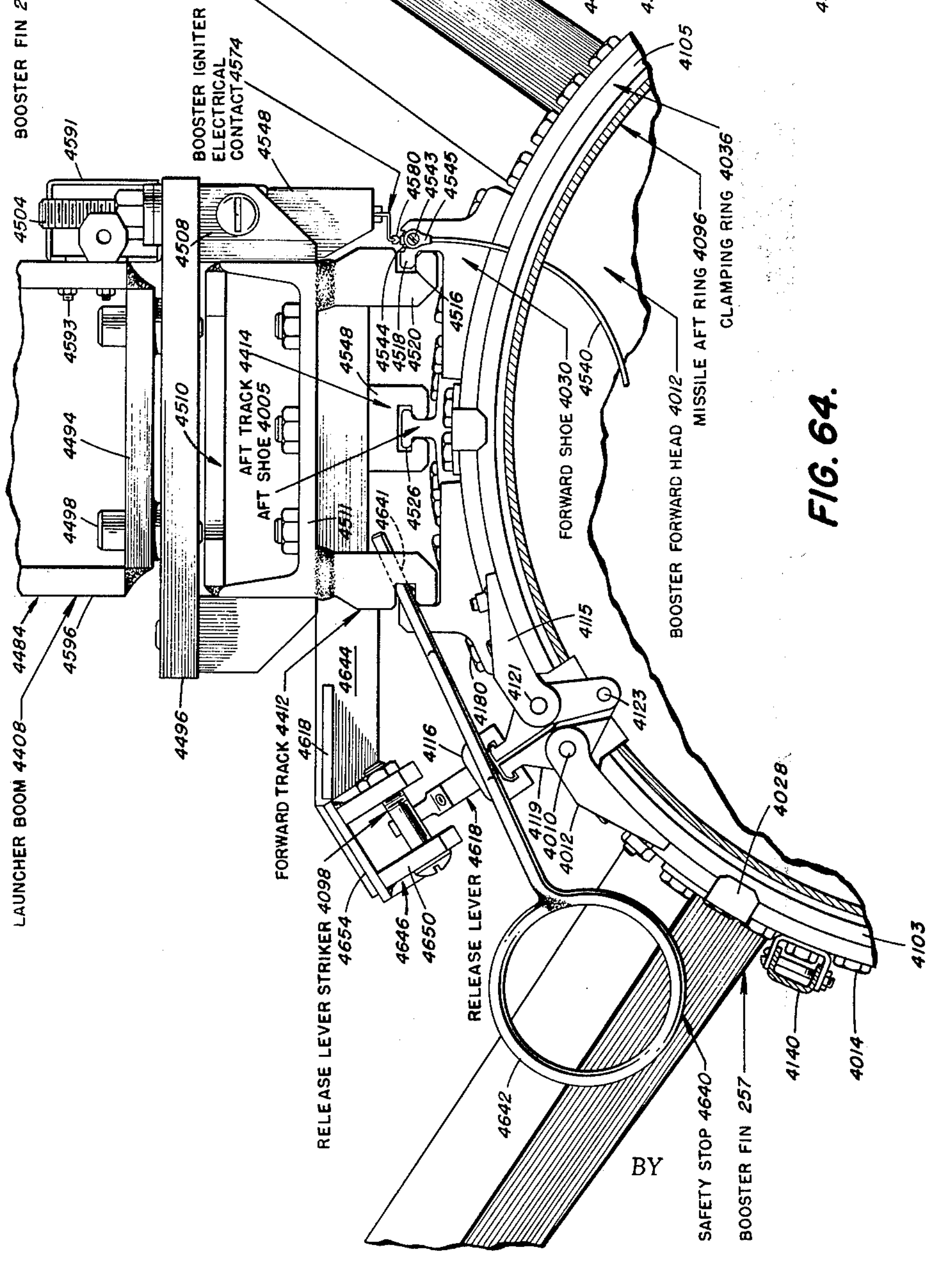

FIG. 64.

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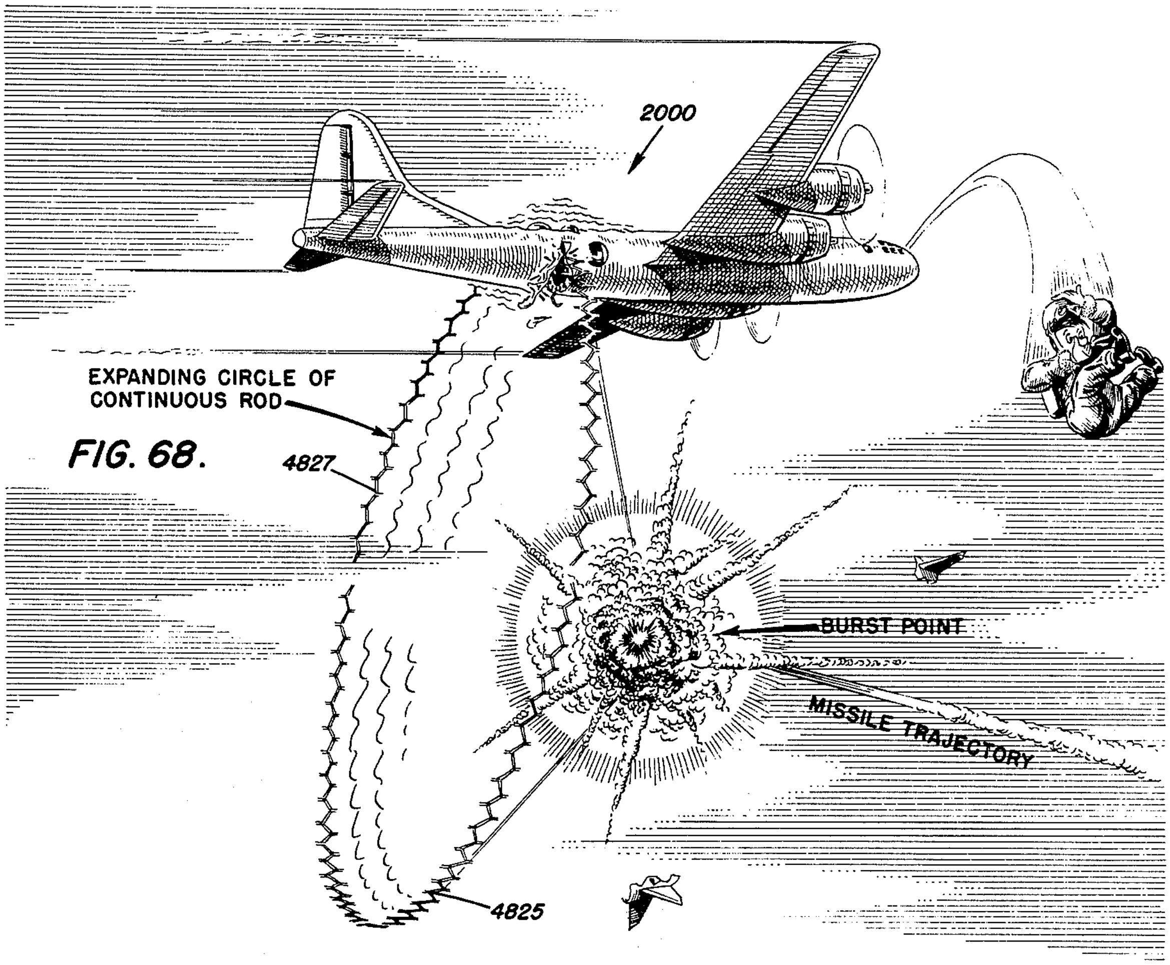
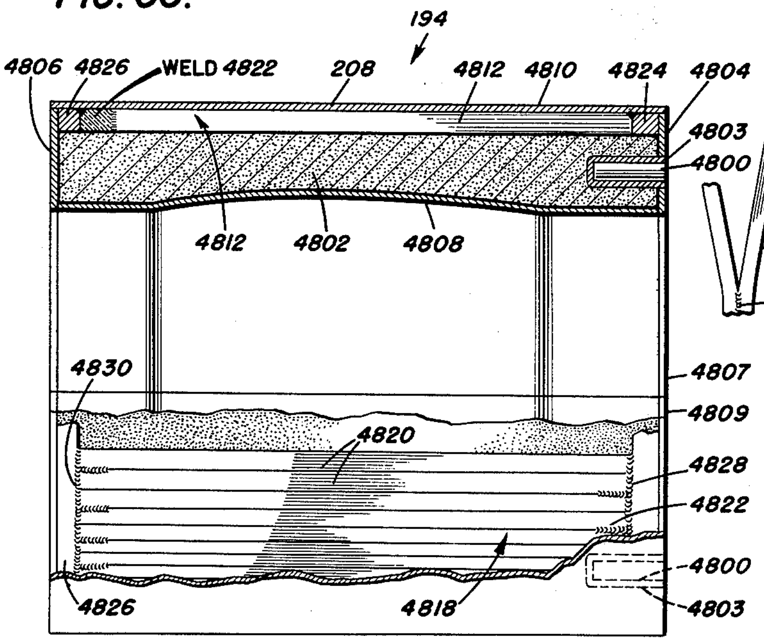


FIG. 68.

FIG. 66.



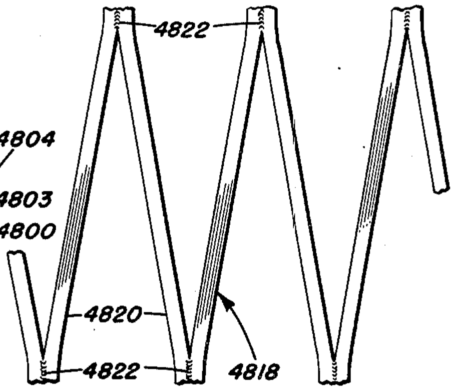


FIG. 67.

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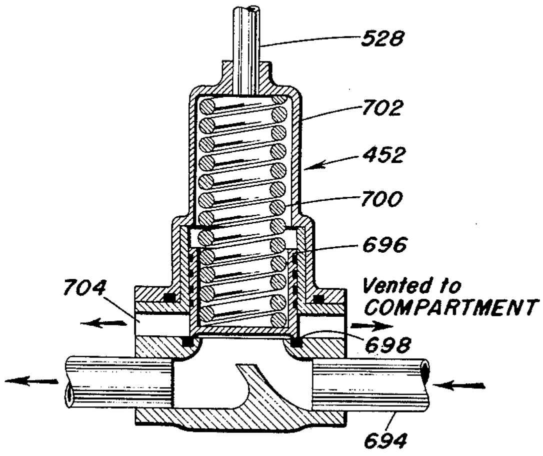

FIG. 69.
NITROGEN RELIEF VALVE

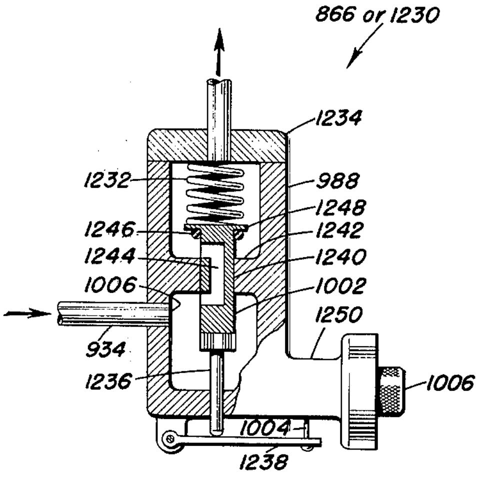

FIG. 70.
SQUIB ACTIVATED TIME DELAY UNIT

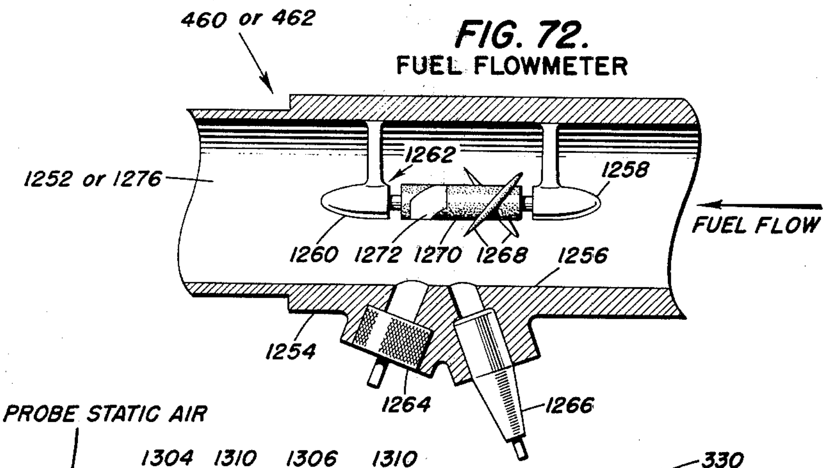

FIG. 72.
FUEL FLOWMETER

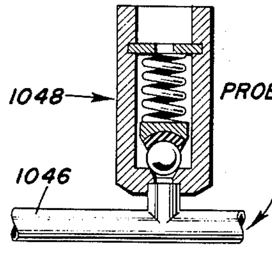

FIG. 71.
PROBE STATIC RELIEF VALVE

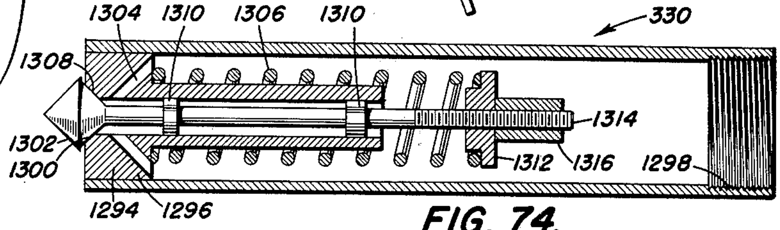

FIG. 74.
PILOT FUEL INJECTOR

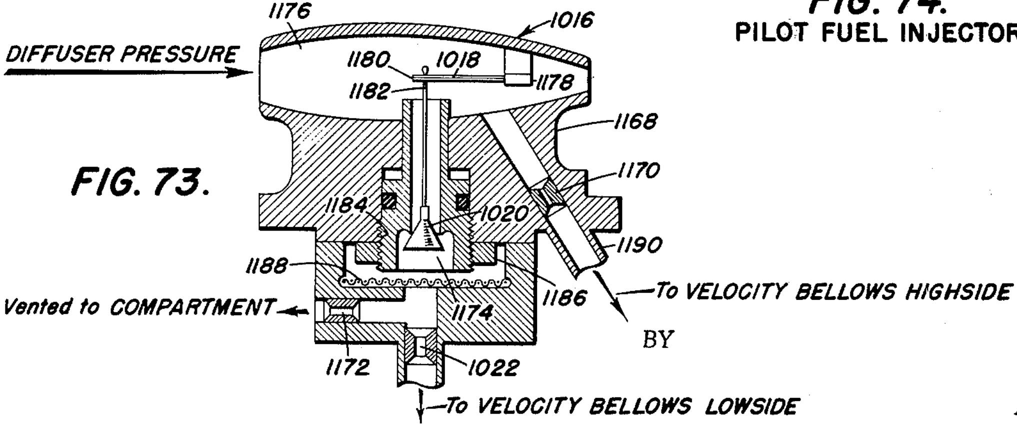

FIG. 73.

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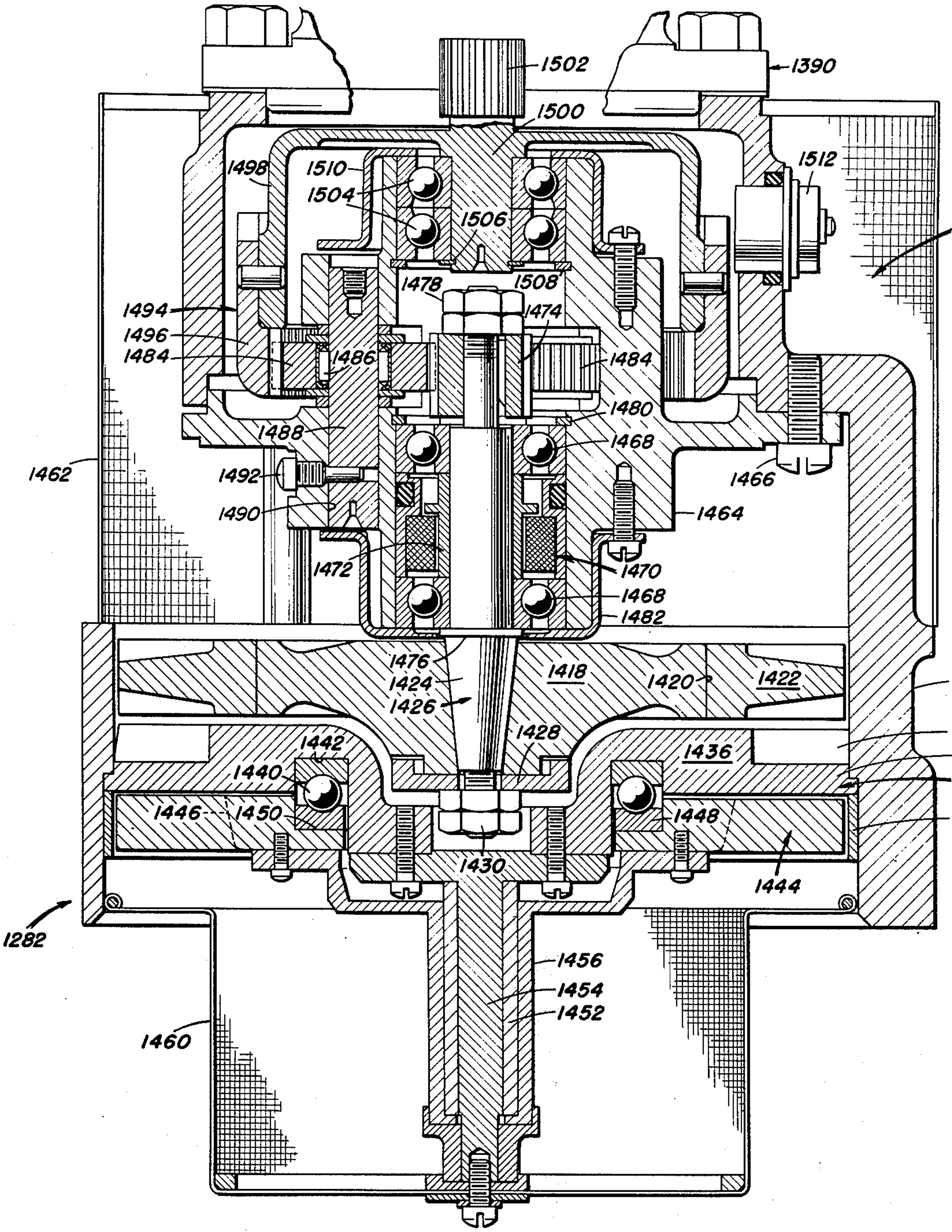

FIG. 76.
TURBINE AND REDUCTION GEAR ASSEMBLY
Hydraulic System

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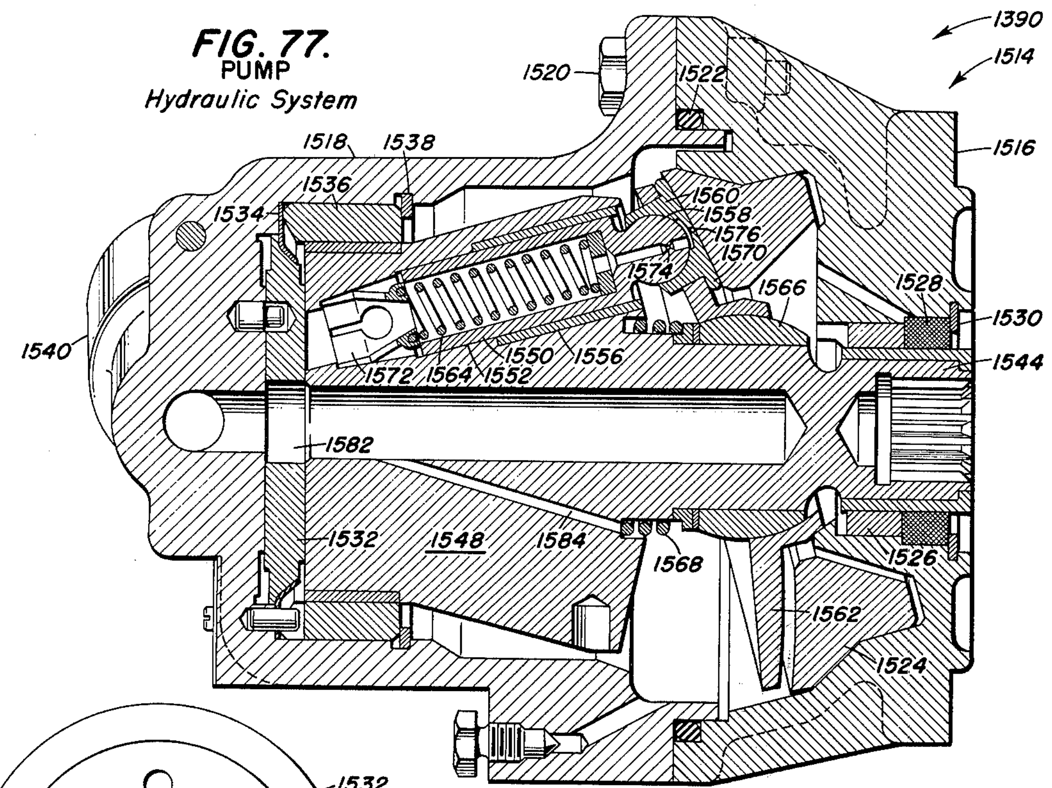


FIG. 77.
PUMP
Hydraulic System

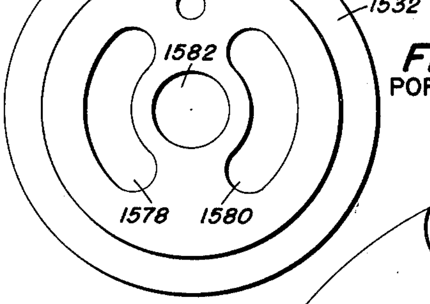


FIG. 79.
PORT PLATE

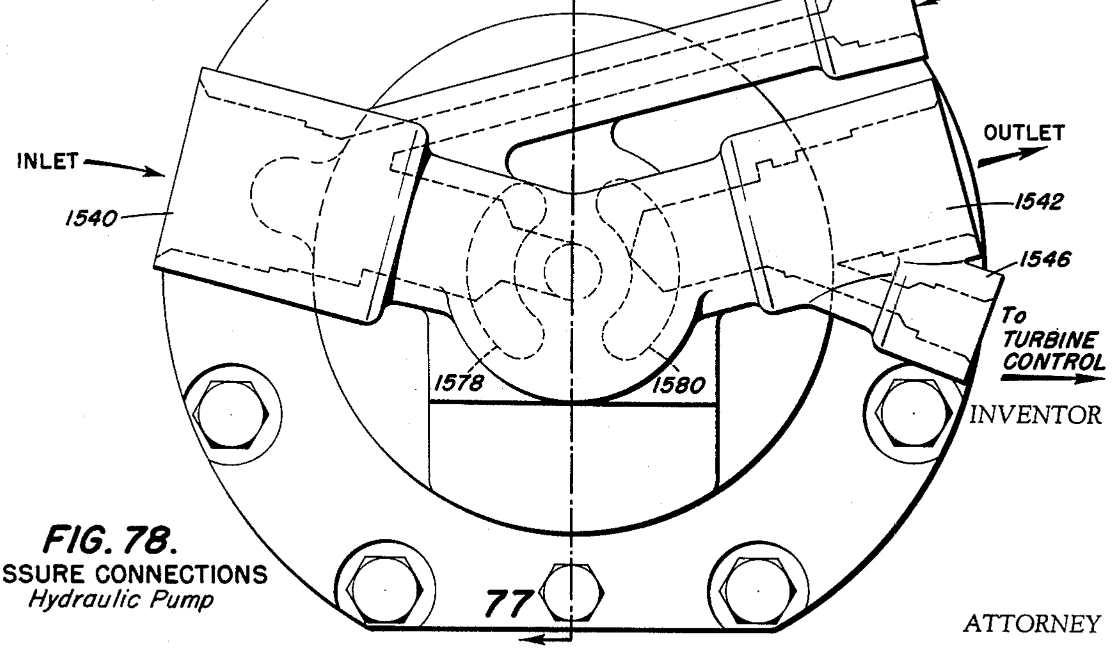


FIG. 78.
PRESSURE CONNECTIONS
Hydraulic Pump

INVENTOR

ATTORNEY

TURBINE CONTROL ASSEMBLY

FIG. 80.

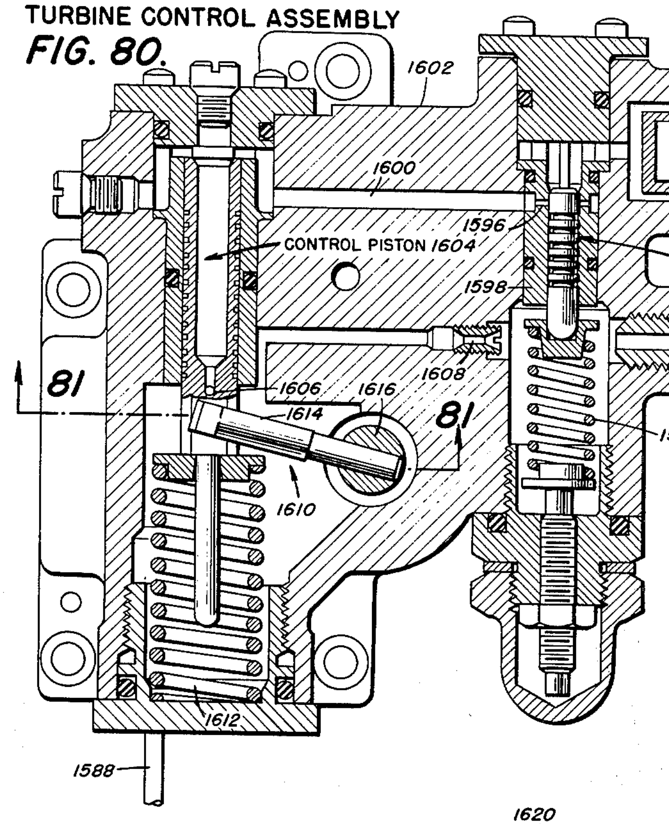
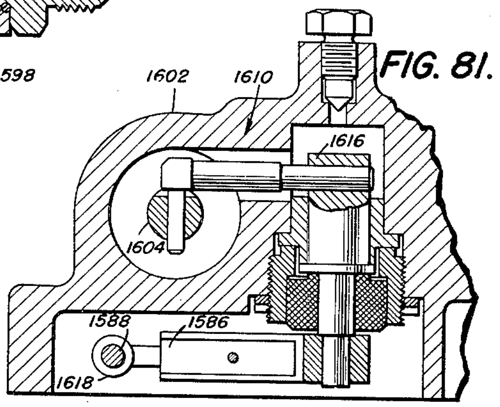


FIG. 81.



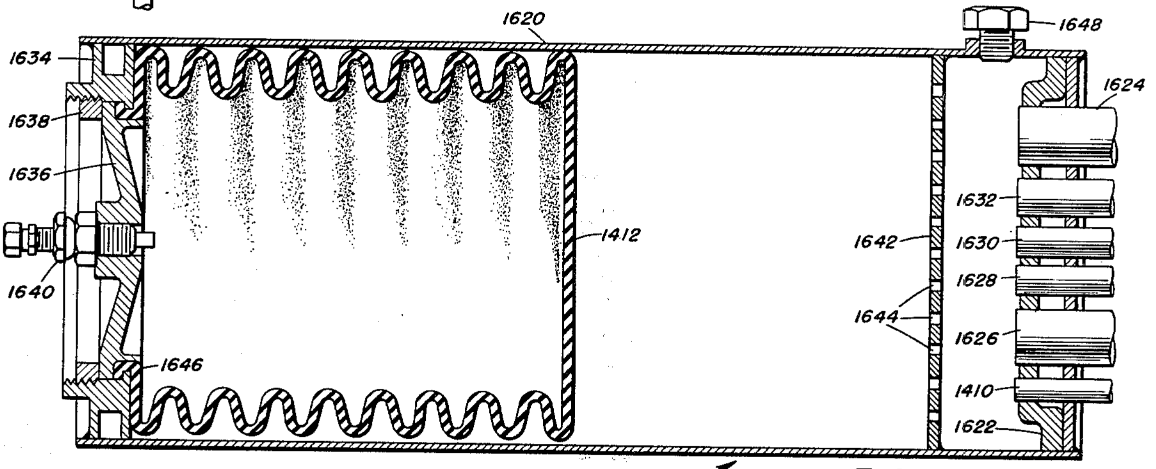


FIG. 82.
HYDRAULIC SUMP

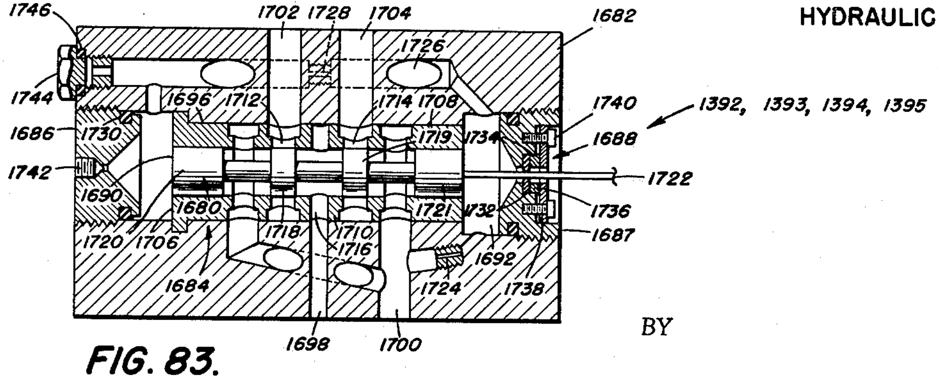


FIG. 83.
TRANSFER VALVE

INVENTOR

BY

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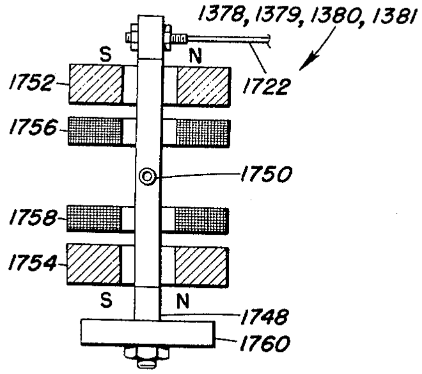


FIG. 84.
TORQUE MOTOR

FIG. 85.
WING ACTUATOR

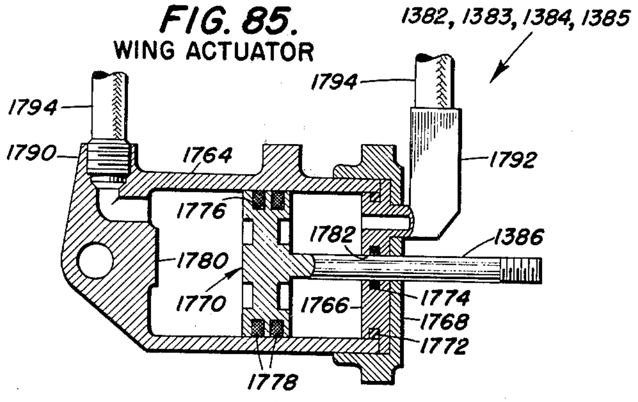
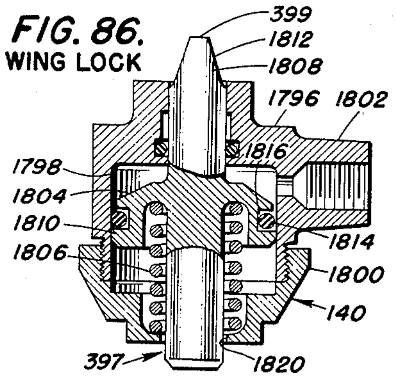


FIG. 86.
WING LOCK



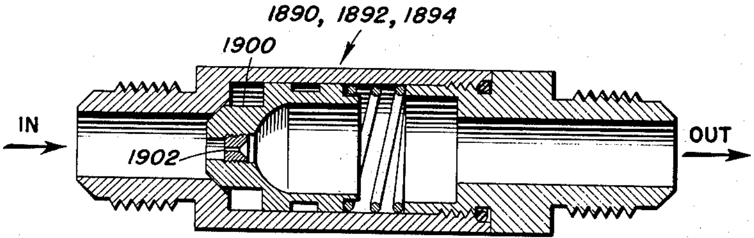


FIG. 88.
CHECK VALVE

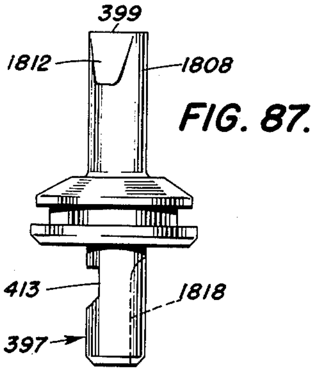
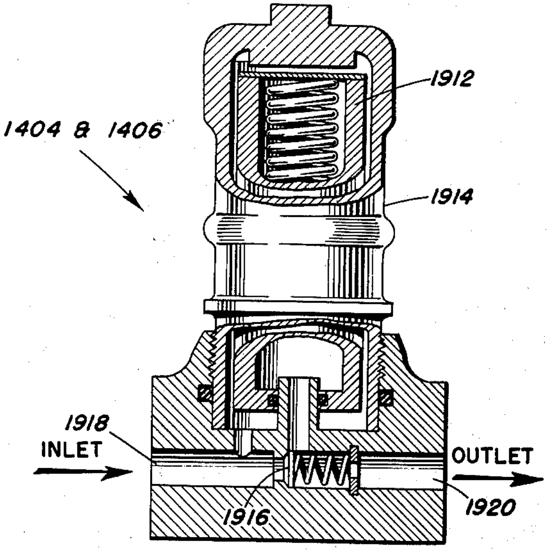


FIG. 87.

FIG. 89.
FILTER



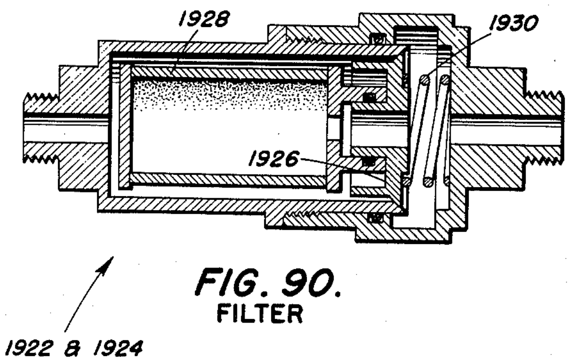


FIG. 90.
FILTER

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BY

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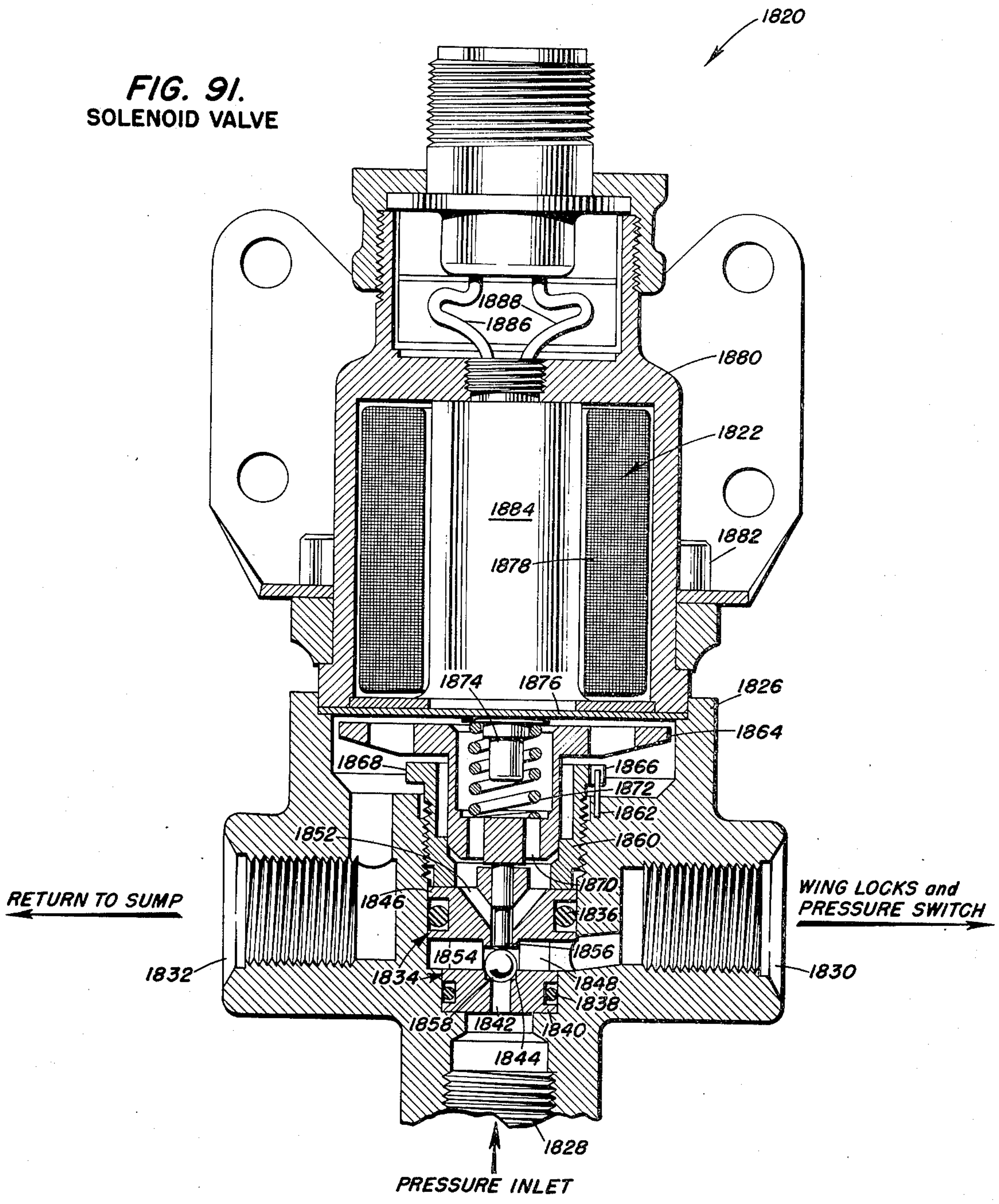
FIG. 91.
SOLENOID VALVE



INVENTOR

BY

ATTORNEY

FIG. 92

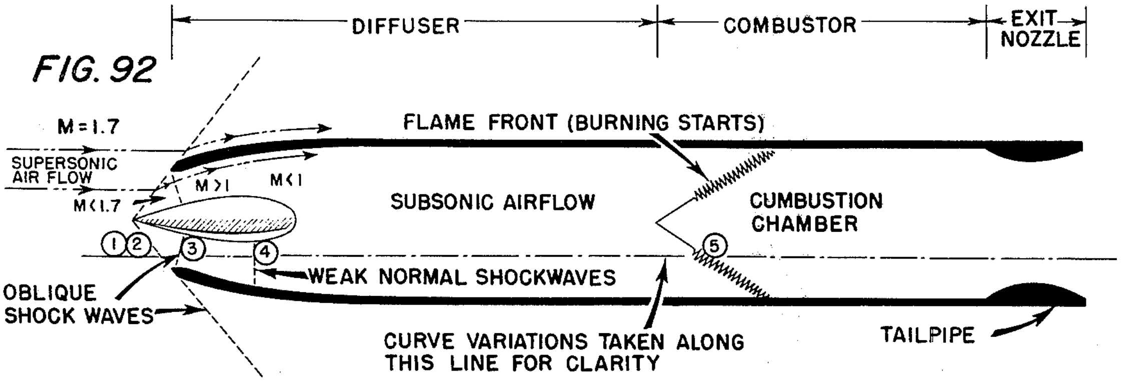
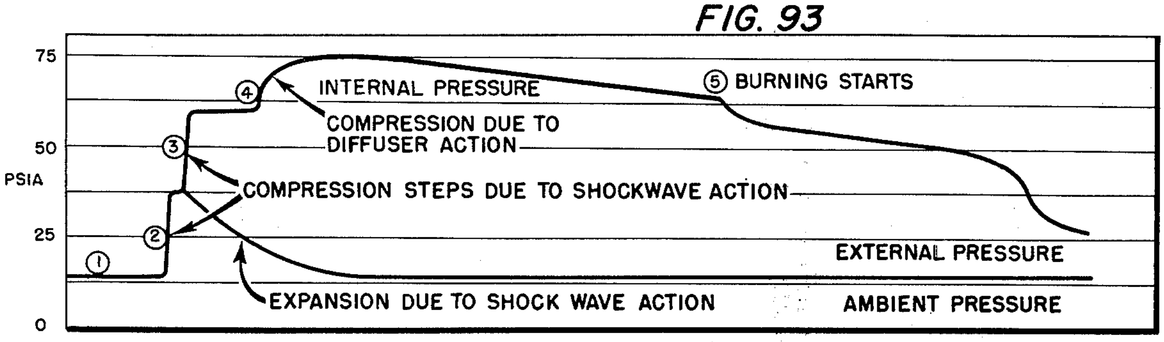
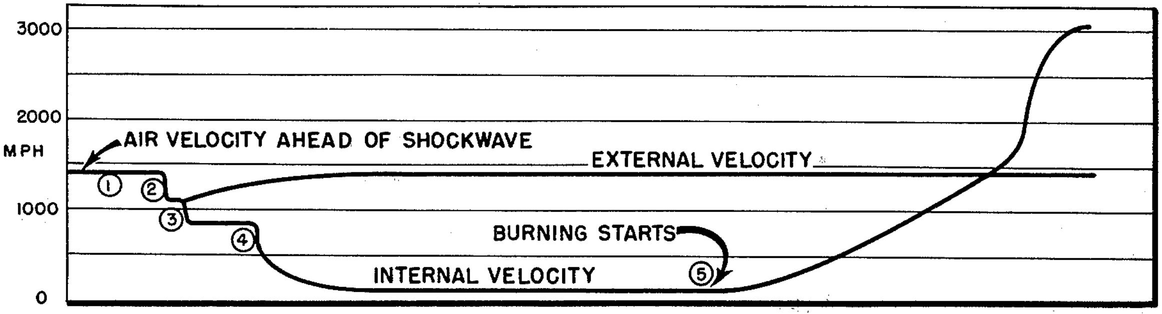


FIG. 93



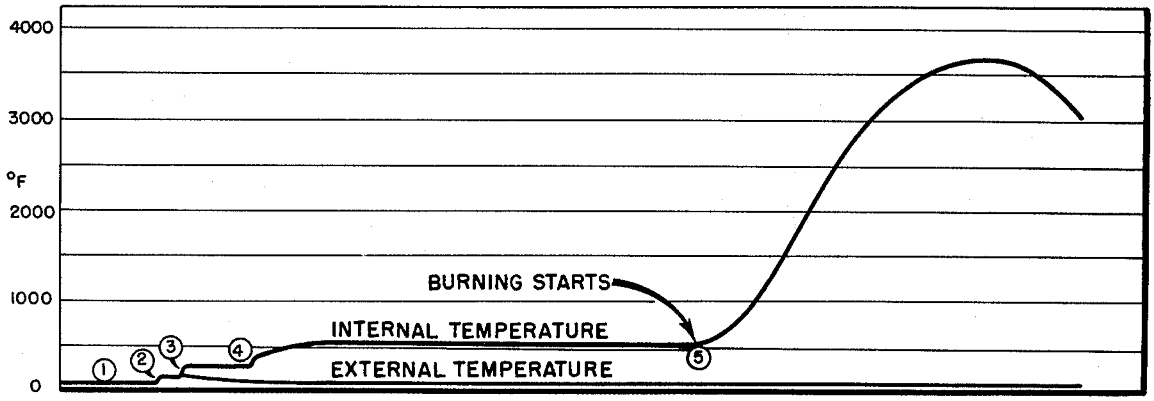
GAS STATIC PRESSURE

FIG. 94



GAS VELOCITY

FIG. 95



GAS TEMPERATURE

ATTORNEY

FIG. 96

DIFFUSER PRESSURE FORCES

F_{LA} = $F_{LATERAL}$

F_{LO} = $F_{LONGITUDINAL}$

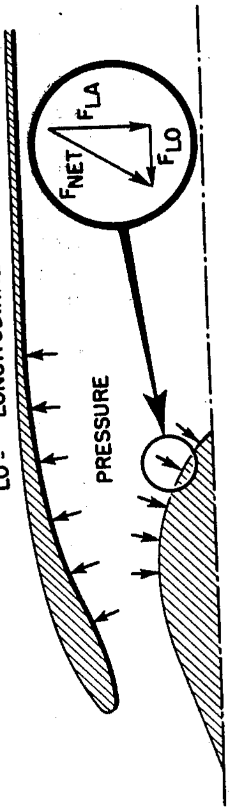
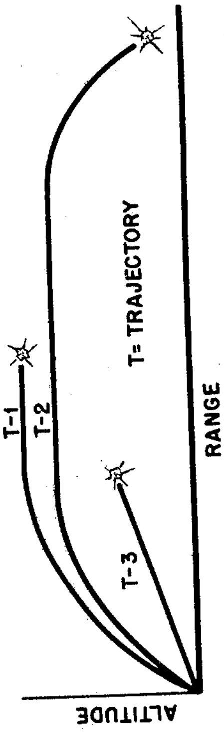
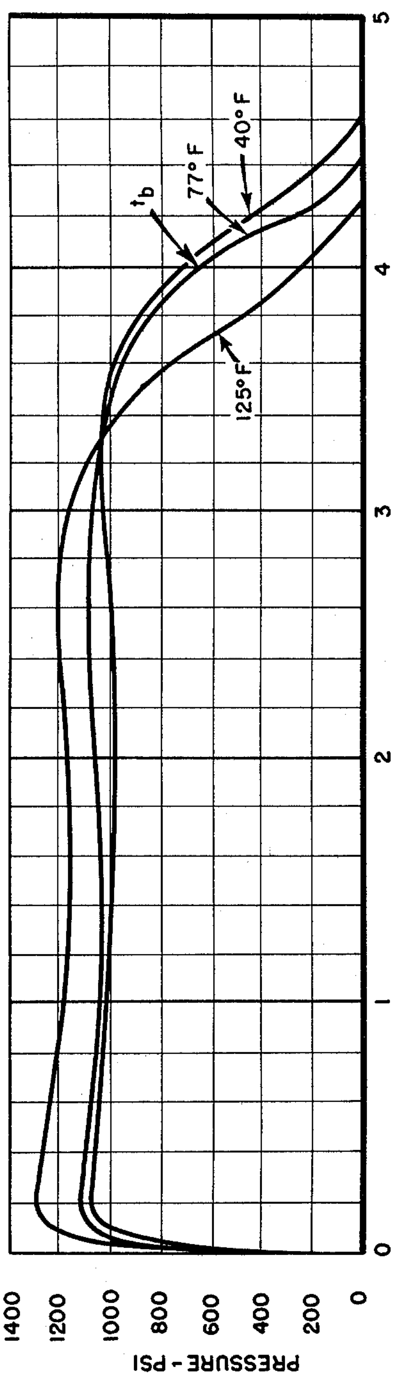


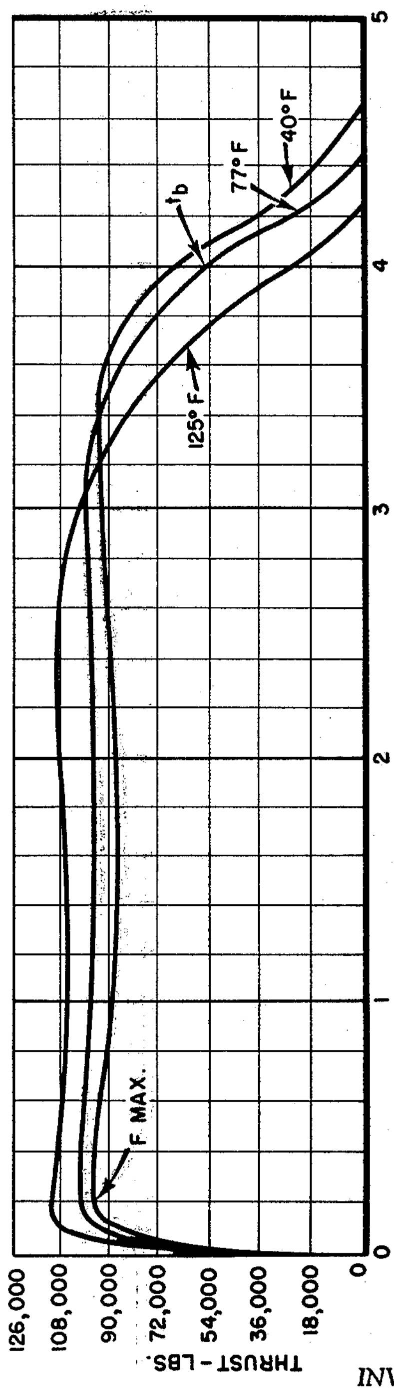
FIG. 97





CHAMBER PRESSURE VS. TIME

FIG. 98



THRUST VS. TIME

FIG. 99

INVENTOR

BY

ATTORNEY

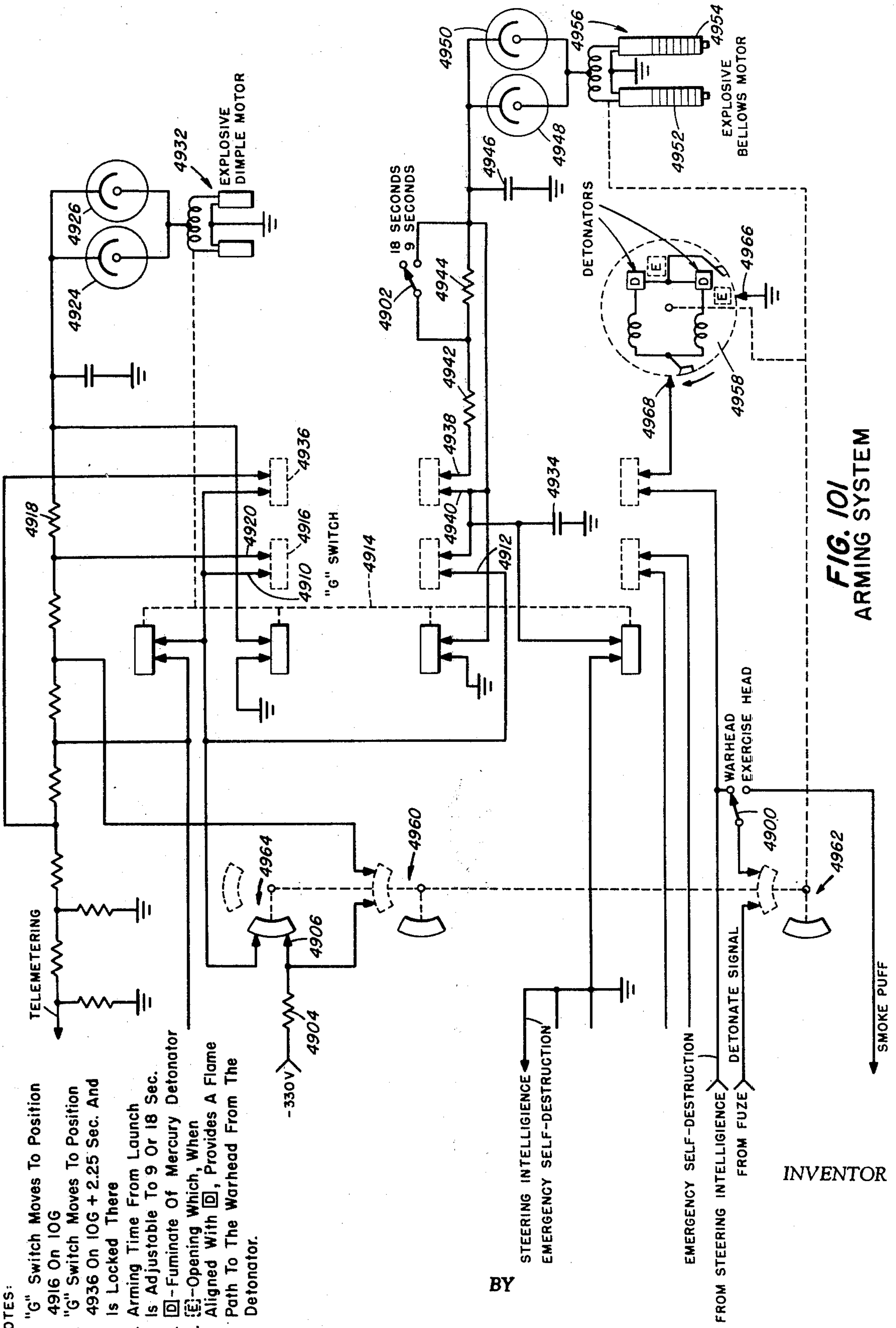


FIG. 101
ARMING SYSTEM

NOTES:
1. "G" Switch Moves To Position 4916 On 10G
2. "G" Switch Moves To Position 4936 On 10G + 2.25 Sec. And Is Locked There
3. Arming Time From Launch Is Adjustable To 9 Or 18 Sec.
4. D-Fuminate Of Mercury Detonator
5. E-Opening Which, When Aligned With D, Provides A Flame Path To The Warhead From The Detonator.

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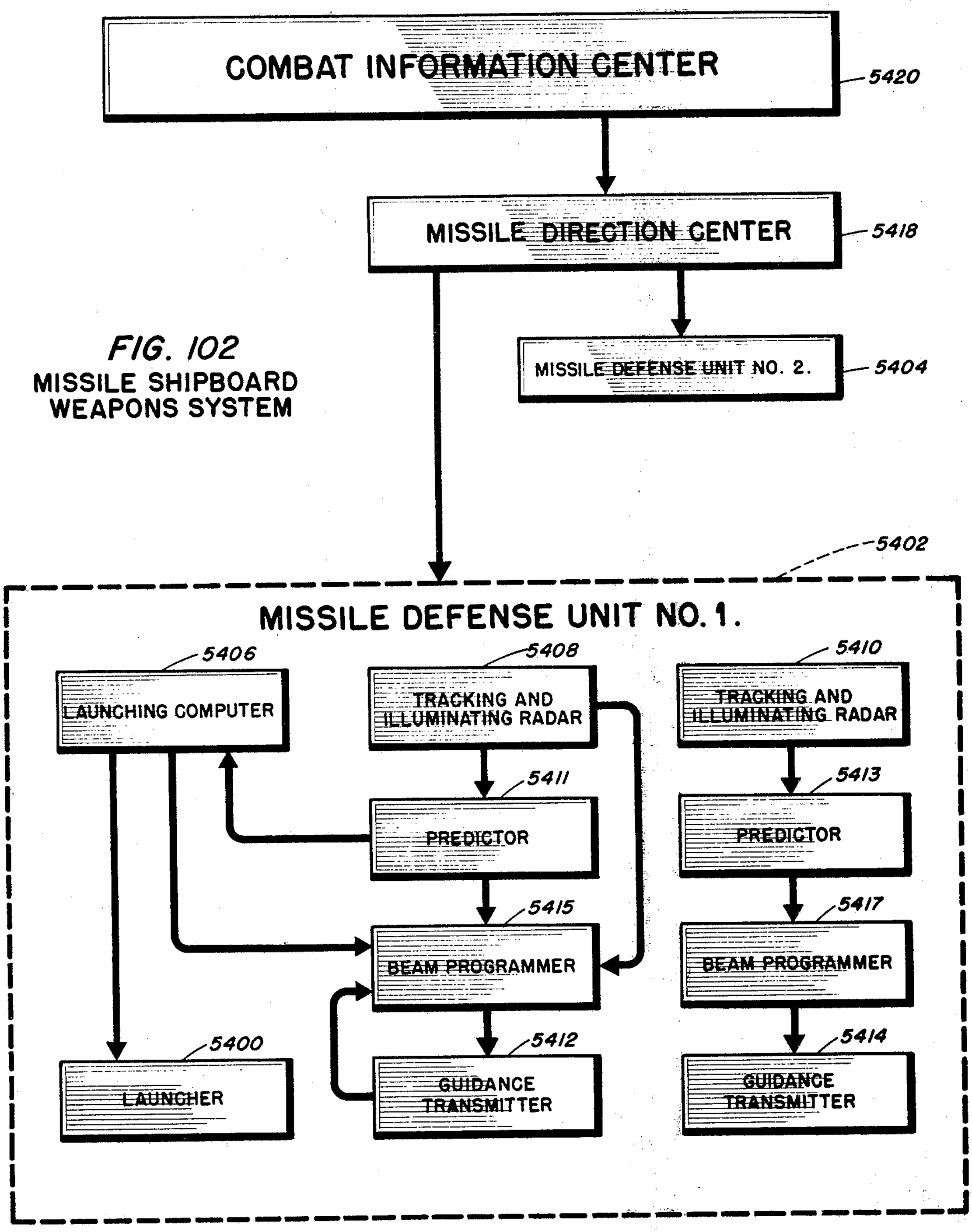


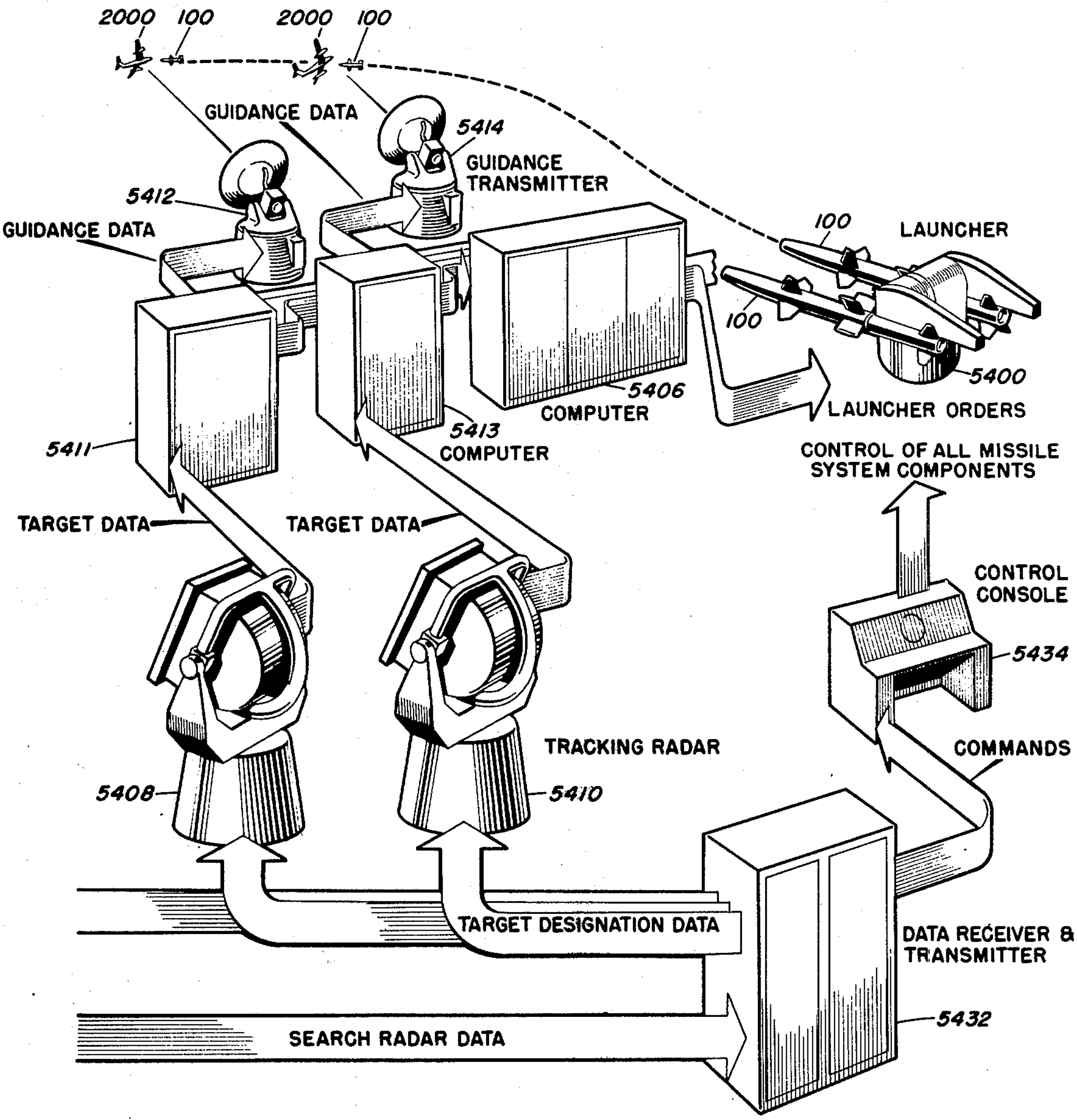
FIG. 102
MISSILE SHIPBOARD WEAPONS SYSTEM

INVENTOR

BY

ATTORNEY

FIG. 103



INVENTOR

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ATTORNEY

MISSILE SHIPBOARD LAUNCHING SYSTEM

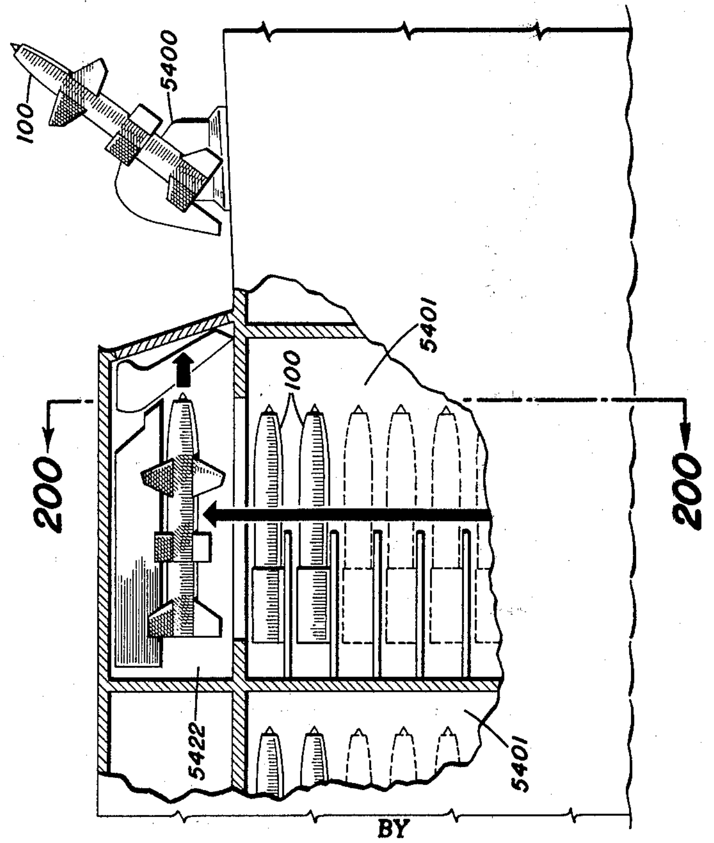


FIG. 104

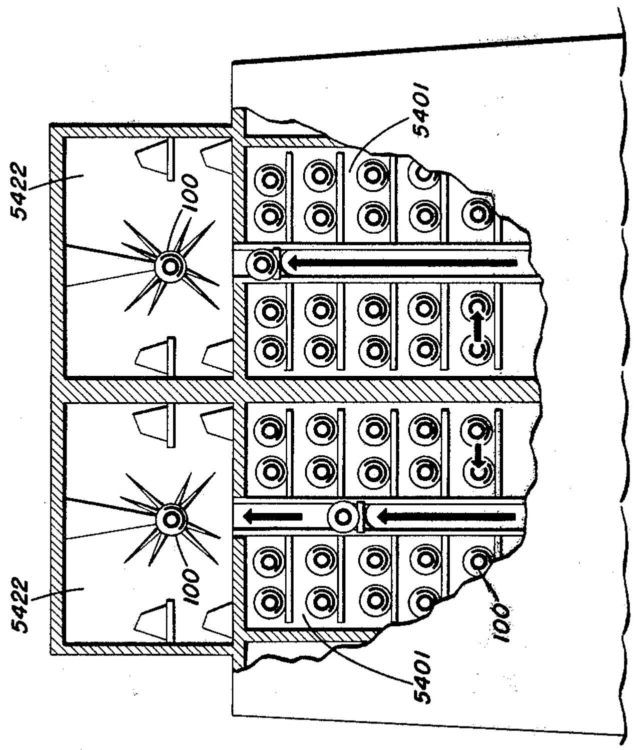
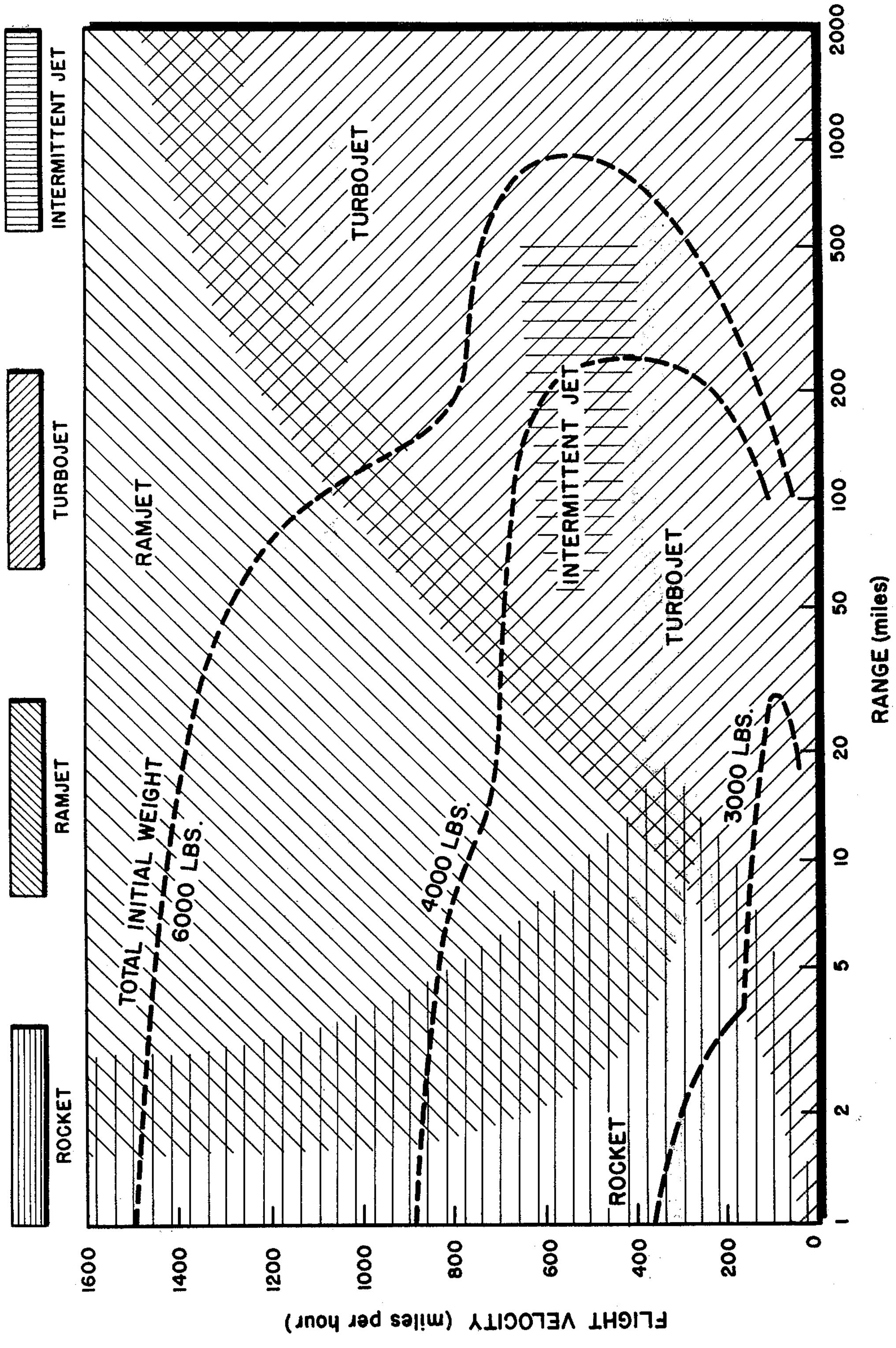


FIG. 105

INVENTOR

BY

ATTORNEY



VELOCITY-RANGE CHARACTERIZATION OF JET-PROPELLED MISSILES

FIG. 106

INVENTOR

BY

ATTORNEY

GUIDED MISSILE

This invention relates generally to aerial guided missiles, and more particularly to ramjet-propelled, supersonic, surface-to-air guided missiles designed to intercept and destroy aircraft carrying guided missiles.

It is an object of this invention, to provide a ramjet-propelled, supersonic, surface-to-air guided missile which is capable of intercepting and destroying high performance aircraft carrying guided missiles.

Another object of this invention is to provide a ramjet-propelled, supersonic, surface-to-air guided missile which is stabilized through the boost phase of aerial flight.

Another object of this invention is to provide an aerial guided missile which is launched directly into a programmed auxiliary beam, other than the tracking radar beam, for capture and midcourse guidance.

Another object of this invention is to provide an aerial missile which utilizes beam-rider guidance during the midcourse phase of flight which is provided by means of an auxiliary radar beam and which acts solely as a transmitter.

Even still another object to this invention is to provide an aerial guided missile in which the guidance beam elevation and azimuth are programmed so as to approach coincidence with the target-tracking radar beam prior to terminal guidance, such that the elevation program permits "up and over" trajectories that are favorable from the standpoint of fuel economy while the azimuth program avoids restrictions in firing direction arising from launching interferences.

Another object of this invention is to provide an aerial guided missile in which semiactive radar interferometer homing is utilized during the terminal phase of flight of the aerial missile to the target, with the target illumination being provided by a tracking radar and in which target discrimination is accomplished by means of the homing equipment through range gating.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a side elevation view of the right hand side of a missile according to the invention and showing the location of the various systems;

FIG. 2 is a front elevation view of the missile showing the arrangement of the wings;

FIG. 3 is a rear elevation view of the missile;

FIG. 4 is an elevation view of the right hand side of the missile shown with the outer skin removed from certain system compartments thereof;

FIG. 5 is a cross sectional view taken on line **5—5** of FIG. 4, and shows the location of the three intelligence systems thereof packages;

FIG. 6 is a sectional view taken on line **6—6** of FIG. 4 and shows the method of mounting the two warhead halves;

FIG. 7 is a fragmentary vertical sectional view taken through the forward end of the missile and the inner body thereof;

FIG. 8 is a fragmentary elevation view of the fuel system portion of the missile and showing the packaging arrangement of the various fuel system components;

FIGS. 9A and 9B considered together, comprise a diagrammatic illustration of the fuel system for the missile;

FIG. 10 is a diagrammatic sectional view of the main fuel regulator;

FIG. 11 is a diagrammatic sectional view of the pilot regulator of the fuel system;

FIG. 12 is a diagrammatic view of a section the turbine fuel pump of the fuel system;

FIG. 13 is a diagrammatic view in section of a fuel shutoff valve of the fuel system;

FIG. 14 is a diagrammatic view in section of a the nitrogen flow control unit of the fuel pressurization system;

FIG. 15 is a diagrammatic illustration showing the inter connected relationship entire hydraulic system;

FIG. 16 is a fragmentary elevation view showing the packaging arrangement of those hydraulic system components disposed between the wings of the missile;

FIG. 17 is a fragmentary elevation view showing the packaging arrangement of those hydraulic system components disposed between the wings of the missile and rotated about the missile axis 90° from the position shown in FIG. 16, with the rotation being from bottom to top, it being noted that the turbine air intake, which appears midway between the wings is on the top centerline of the missile when the missile is in normal flight position;

FIg. 18 is a fragmentary elevation view showing the packaging arrangement of those hydraulic system components disposed between the wings rotated bottom to top about the missile axis 90° from the position shown in FIG. 17;

FIG. 19 is a fragmentary elevation view showing the packaging arrangement of those hydraulic system components disposed between the wings and with the plane of view rotated bottom to top about the missile axis through an angle 90° from the position shown in FIG. 18;

FIG. 20 is a fragmentary view in elevation with portions thereof broken away and shown in cross section as taken through the missile along line **20—20** of FIG. 18 and showing the arrangement of the hydraulic wing actuators;

FIG. 21 is a fragmentary view with portions thereof in section as taken on line **21—21** of FIg. 20 and showing the manner in which a hydraulic wing actuator is secured to the wing mounting bulkhead and one of the wing spars of a missile;

FIG. 22 is a fragmentary view with portions thereof broken away and in section illustrating, on a greatly enlarged scale, the main wing quick attach device;

FIG. 23 is a fragmentary view with portions thereof in section as taken along line **23—23** of FIG. 22;

FIG. 24 is a fragmentary view providing a showing similar to that of FIG. 23, with the exception that the latch levers and latch lever catches for wing attachment purposes are shown in a released position which would permit removal of the wing;

FIG. 25 is somewhat similar to FIg. 22 and shows the wing lock installation;

FIG. 26 is an axial section through the missile fuel tank and fuel pressurization compartment, many of the elements being shown in elevation;

FIG. 27 is a cross section taken on line **27—27** of FIg. 26 looking in the direction of the arrows and shows the packaging arrangement of the various fuel pressurization system components;

FIG. **28** is a fragmentary cross section taken on line **28—28** of FIG. **26** looking in the direction of the arrows, showing the bladder filling ports;

FIG. **29** is a fragmentary cross section taken on line **29—29** of FIG. **26** looking in the direction of the arrows, showing the fuel collection area;

FIG. **30** is a further section through the fuel collection area and is taken along line **30—30** of FIG. **29**;

FIG. **31** is an axial section through the entire combustor section of the missile with many of the components being shown in elevation;

FIG. **32** is a perspective of the pilot fuel distributor, the secondary fuel distributor, and the shroud arranged in an assembled position, certain portions being shown in section or broken away;

FIG. **33** is a perspective of the combustor pilot assembly, certain portions being broken away;

FIG. **34** is a perspective of the combustor central can assembly with portions broken away;

FIG. **35** is an axial section through the secondary fuel distributor valve;

FIG. **36** is a perspective of the combustor outer shroud assembly with a portion broken away;

FIG. **37** is an elevation of the tailpipe assembly, shown as having been rotated 180° from normal about the missile axis, with a portion being shown in section and further showing the arrangement of the coaxial cables and connections to the telemetering notch antennae;

FIG. **38** is a section through the missile tailpipe taken on the centerline of one of the fin supports, with the fin being shown in elevation;

FIG. **39** is a fragmentary cross section through the fin latching device taken on line **39—39** of FIG. **38**, looking in the direction of the arrows;

FIG. **40** is a fragmentary cross section taken on line **40—40** of FIg. **38**, showing in detail the connecting means between the coaxial cables of the missile body and a fin;

FIG. **41** is a detailed fragmentary elevation of the telemetering notch antenna on a greatly enlarged scale with the outer fin skin and antenna cover plate removed from the near side;

FIG. **42** is still a further enlarged cross section taken on line **42—42** of FIG. **41** through the telemetering notch antenna;

FIGS. **43A**, **43B**, **43C** and **43D** comprise a single erection flow diagram showing the manner in which all the various missile sub-assemblies are brought together to form the complete ramjet missile assembly which appears at the bottom of FIG. **43D**, with all of the above assemblies being shown in perspective;

FIG. **44** is a side elevation of the missile and booster connected together, in an "on launcher" position;

FIG. **45** is a rear elevational view of FIG. **44**;

FIG. **46** is a cross section on an enlarged scale, taken on line **46—46** of FIG. **44** looking in the direction of the arrows, through the missile aft clamping ring;

FIG. **47** is a longitudinal section taken on line **47—47** of FIG. **46** through the aft end of the missile and the forward end of the booster with certain elements being shown in elevation;

FIG. **48** is a fragmentary front elevational detail view, on an enlarged scale, of the missile-booster clamp ring release mechanism;

FIG. **49** is a longitudinal section taken on line **49—49** of FIG. **48** looking in the direction of the arrows;

FIG. **50** is a plan view of the mechanism shown in FIGS. **48** and **49**;

FIG. **51** is a fragmentary longitudinal section, on an enlarged scale taken on line **51—51** of FIG. **46** looking in the direction of the arrows through the missile aft ring and booster forward head showing the means for indexing the booster to the missile;

FIG. **52** is an elevation of the detail shown in FIG. **51**;

FIG. **53** is a detailed longitudinal section, on an enlarged scale taken on line **53—53** of FIG. **46**, looking in the direction of the arrows through the aft and forward end of the missile and booster, respectively, illustrating the booster-missile separation signal arrangement;

FIG. **54** is a fragmentary plan of the arrangement shown in FIG. **53**;

FIG. **55** is a fragmentary cross section taken on line **55—55** of FIG. **53**;

FIG. **56** is a fragmentary longitudinal section, on an enlarged scale, through the aft and forward section of the missile and booster, respectively, illustrating the means employed to insure concentric spreading of the clamping ring upon missile-booster separation, and is taken on line **56—56** of FIG. **46** looking in the direction of the arrows;

FIG. **57** is a fragmentary cross section taken on line **57—57** of FIG. **56** looking in the direction of the arrows through the detail illustrated in FIG. **56**;

FIG. **58** is a sectional view taken on line **58—58** of FIG. **56** looking in the direction of the arrows further illustrating the details shown in FIGS. **56** and **57**;

FIG. **59** is an axial cross section taken on line **59—59** of FIG. **47** looking in the direction of the arrows through the forward end of booster;

FIG. **60** is a longitudinal section through the booster shroud, with the nozzle portions thereof being shown in elevation;

FIG. **61** is a side elevation, on an enlarged scale, of the launcher;

FIG. **62** is a detailed fragmentary elevation of the launching shoes and track;

FIG. **63** is a plan of the arrangement shown in FIG. **62**;

FIG. **64** is an axial section taken on line **64—64** of FIG. **62** looking in the direction of the arrows;

FIG. **65** is a cross section, on an enlarged scale, taken on line **65—65** of FIG. **62** illustrating the details of the booster igniter electrical contact;

FIG. **66** is a cross section, partially in elevation, of the warhead;

FIG. **67** is a side view of the rod assembly in a partially extended condition;

FIG. **68** is a pictorial perspective illustrating the manner in which the rods of FIG. **67** expand in semicircular ring sections upon detonation of the warhead;

FIG. **69** is a section through the nitrogen relief valve of the fuel pressurization system;

FIG. **70** is a section through one of the squib activated time delay units of the fuel system, certain elements being shown in elevation;

FIG. **71** is a section through the probe static relief valve of the fuel system;

FIG. **72** is a section through one of the flowmeters of the fuel system;

FIG. **73** is a section through the temperature pick-up of the main regulator of the fuel system;

FIG. **74** is a section through one of the pilot fuel injectors of the fuel system;

FIG. **75** is a section through one of the main injector nozzles of the fuel system;

FIG. **76** is an axial section through turbine and reduction gear assembly of the hydraulic system;

FIG. **77** is an axial section through the pump of the hydraulic system taken on line **77—77** of FIG. **78** looking in the direction of the arrows;

FIG. **78** is an end elevation of the hydraulic system pump illustrating the various pressure connections;

FIG. **79** is a detail elevation of the port plate in the hydraulic system pump illustrated in FIG. **77**;

FIG. **80** is a section through the turbine control assembly of the hydraulic system;

FIG. **81** is a fragmentary section taken on line **81—81** of FIG. **80** looking in the direction of the arrows;

FIG. **82** is an axial section through the pump of the hydraulic system;

FIG. **83** is a semi-schematic axial section through one of the transfer valves of the hydraulic system;

FIG. **84** is a simplified schematic section through one of the torque motors of the hydraulic system;

FIG. **85** is a simplified axial section through one of the wing actuators of the hydraulic system;

FIG. **86** is an axial section through one of the wing locks of the hydraulic system;

FIG. **87** is a detail elevation of the piston and rod in the wing actuator illustrated in FIG. **86**;

FIG. **88** is an axial section through one of the check valves of the hydraulic system;

FIG. **89** is an axial section through one of the filters of the hydraulic system, certain elements being shown in elevation;

FIG. **90** is an axial section through a second type of filter used in the hydraulic system;

FIG. **91** is an axial section through the solenoid valve of the hydraulic system;

FIG. **92** is a longitudinal section of a ramjet;

FIG. **93** is a plot of pressure of the air versus distance of travel along the ramjet illustrated in FIG. **92**;

FIG. **94** is a plot of velocity of the air versus distance of travel along the ramjet illustrated in FIG. **92**;

FIG. **95** is a plot of temperature of the air versus distance of travel along the ramjet illustrated in FIG. **92**;

FIG. **96** is a longitudinal section through forward part of a ramjet illustrating the pressure forces in the diffuser;

FIG. **97** illustrates plots of various trajectories of the missile;

FIG. **98** illustrates plots of chamber pressure as a function of time for the booster propellant;

FIG. **99** illustrates plots of thrust developed as a function of time for the booster;

FIG. **100** is a schematic of the ignition circuit for the booster illustrated on sheet **39**;

FIG. **101** is a schematic of the safety and arming system for the missile;

FIG. **102** is a block diagram of the shipboard weapons system for the missile;

FIG. **103** is a diagrammatic perspective of a shipboard control system for the missile;

FIG. **104** is a fragmentary side elevation of a shipboard launching system;

FIG. **105** is a fragmentary front elevation of the shipboard launching system illustrated in FIG. **104**; and

FIG. **106** illustrates graphical representations of velocity-range characterizations for jet-propelled missiles.

GENERAL SUMMARY OF THE MISSILE

In accordance with the invention, there is provided a supersonic, surface-to-air, guided missile, launched by a solid-fuel booster, propelled by a ramjet engine, and deriving guidance intelligence from a ground-based radar system.

This missile is guided to its target in two phases, that is, a midcourse radar beam riding phase which brings the missile into approximate alignment with the target; and then, a homing phase for final guidance to the target.

The missile is provided with four wings 90° apart and four fixed fins arranged in line with the four wings. The incidence angles of the wings are independently controllable, the wings being rotable about shafts disposed to protrude from the edge thereof which is normally in adjacency to the body of the missile and which shaft extends along an axis normal to the line of flight of the missile. Oppositely disposed wings moving together effect guidance control, and when moving differentially effect roll control. One pair of wings steers in the "A" channel (up-left, down-right), while the other pair of wings steers in the "B" channel (up-right, down-left).

For launching of the missile, a booster is suspended on a launcher rail by shoes near the fore and aft ends of the booster. The missile is suspended as a cantilever beam by means of a clamp ring that joins the aft end of the missile to the forward end of the booster. Upon missile launching, the clamp ring is opened, and the missile-booster combination is held together by acceleration forces until the booster propellant is expended.

Propulsion for the missile occurs in two stages. A solid-fuel booster launches the missile and accelerates it to the approximate operating speed of the ramjet engine. The ramjet engine then takes over and maintains active propulsion of the missile for the remainder of the flight of the missile to the aerial target.

The main propulsion of the missile is by its ramjet engine. Fuel is supplied to the pilot and main stages of the combustor of the ramjet engine through separate injection and regulator systems from a common supply system.

Referring now to FIGS. **1, 2, 3, 4, 5, 6, 43A, 43B, 43C,** and **43D** of the drawings, there is illustrated, in general, a missile **100** comprising the present invention. It is a ramjet, propelled, supersonic, surface-to-air guided missile for interception and destruction of aircraft carrying guided missiles or other types of destructive missiles.

The airframe assembly for the missile **100** is comprised of a number of major assemblies for ease of manufacturing and assembly, namely a forward body assembly **102** (including a nose section **104**), a central body assembly **106**, a combustor assembly **108**, an aft body assembly **110**, wing assemblies **112, 113, 114,** and **115**, and fin assemblies **116, 117, 118,** and **119**.

The forward body assembly **102** includes an inner body **120** including an accumulator **122**, homing antennae **124** and waveguide **125**, a static pressure probe **126**, a ram pressure probe **128**, body static pressure taps **130,** a safety and arming device **132,** a guidance system compartment **134,** and a cover **135.**

The center body assembly **106** comprises a center body **136** and a fuel tank **138,** four wing locks **140** and brackets **142,** an aft diffuser body **144,** four wing actuators **1382, 1383, 1384** and **1385,** four wing bearing sleeves **341,** a center compartment cover **150,** an aft compartment cover **152,** and by-pass fairings **154.**

The combustor assembly **108** is comprised of a forward shroud assembly **156,** an outer shroud assembly **158,** a pilot assembly **160,** a central can assembly **162,** and concentric fuel lines **164** and **166** to pilot injectors **330** and main fuel injectors **386,** respectively, while the aft body assembly **110** includes a tailpipe **168,** four fin supports **170,** and a convergent-divergent exit nozzle **172.**

Each of the four wing assemblies **112, 113, 114,** and **115** are provided with a quick attachment device **174,** while the fin assemblies **116, 117, 118,** and **119** are provided with a fin attachment device **176** for each fin, and an antenna **178** for the beam riding system. Fins **116** and **118** are further provided with flare holders **180.**

The body nose section **104** of the missile **100** includes compartments for a missile fuze system **182,** which includes eight fuze antennae **184,** collector rings **186,** fuze electronics packages **188,** and a fuze compartment cover **190;** a safety and arming system **132,** and the missile homing antennae system **124.** The inner body **120** of the missile **100** is located in the body nose section **104,** as will be pointed out more in detail subsequently.

The forward body assembly **102** of the missile **100** has a compartment **192** provided therein for housing a missile warhead system **194,** or an exercise head assembly **196** including an exercise head structure **198,** two telemeters **200** and **202,** a distribution panel chassis **204,** telemetering equipment **206,** and two covers **208** and **210,** therefor. Compartment **134** is provided for housing a steering intelligence system **212,** a guidance control system **214,** and an electrical power system **216.**

In the center body assembly **106** of the missile **100,** there is contained a compartment **218** for a hydraulic system **220;** and compartments **222, 224,** and **226** for a fuel system comprising the fuel tank **138,** a fuel pressurization system **228,** and a fuel control system **230,** respectively. Hydraulic system compartment **218** and fuel control system compartment **226** are both located between the bulkheads **308** and **310** of center body assembly **106.** In addition, the center body assembly **106** has mounted thereon the wings **112, 113, 114,** and **115** for steering the missile **100** along its trajectory to the target.

The aft body assembly **110** of the missile **100,** as previously indicated, includes the tailpipe **168,** with the four fixed fins **116, 117, 118,** and **119** mounted thereon, and the convergent-divergent exit nozzle **172.** The combustor assembly **108** is located within the rear portion of the center body assembly **106** and the forward portion of the aft body assembly **110.**

The missile airframe structure, FIGS. **1, 3, 44, 45,** and **46,** is comprised of the missile body **101,** the four wings **112, 113, 114,** and **115,** the four fixed fins **116,** 117, 118, and **119;** and all of the structural provisions for installation of missile equipment, including all the structurally integral missile equipment. In conjunction with the missile booster **500,** the airframe includes all fixed and removable missile-booster handling fittings; missile-booster structural and electrical connections and clamp ring **4036;** forward and aft launching shoes **4030** and **4005,** respectively, for the booster **500;** four fixed fins **256, 257, 258,** and **259;** booster body **501;** the nozzle **4000;** and forward and aft handling shoes **4032** and **4007,** respectively, for the booster **500.**

The missile airframe structure also includes the inner duct **226,** which has an inlet **268,** a diffuser **270,** a combustion chamber **272,** and the convergent-divergent exit nozzle **172** located therein.

The inner duct **266** extends throughout the length of the missile **100** and is defined by the duct wall **274.** Referring to FIGS. **1, 4,** and **7,** for purposes of illustration this duct **266** is divided into several main sections, namely, a cowl lip **276,** a short conical section **278,** a cylindrical intermediate section **280,** and intermediate divergent or conical section **282,** a second larger cylindrical section **284,** and the convergent-divergent exit nozzle section **172,** proceeding from the forward to the aft end of the missile **100.** The second larger cylindrical section of the duct **266** includes the combustion chamber **272,** and the tailpipe **168,** while the other sections of the duct include the various stages of the diffuser **270,** as will be described subsequently.

The surrounding skin **286** of the missile **100** defines the outer wall of the missile. At the nose section **104** of the missile **100,** the outer wall **286** converges along a curve towards the inner wall. The forward ends of the outer skin **286** and inner duct **266,** as best seen in FIG. **7,** are attached to annular flanges **288** and **290** by welding or by means of screws. These flanges are integral with the cowl lip **276.** The outer surface **292** of the outer skin **286** of the missile **100** is a continuation of the outer surface **294** of the cowl lip **276,** while the inner surface **296** of the duct wall **274** is a continuation of the inner surface **298** of the cowl lip **276.**

The cowl lip **276** defines the circular inlet **268** of the duct **266.** At the rear of the missile **100,** FIG. **37,** the convergent-divergent nozzle **172** is secured by welding near the rear of the cylindrical section **284** of the duct **266,** and defines a circular outlet **300** for the missile duct **266.** This outlet **300** is used as an escape for the gases, which are liberated by the burning of the fuel.

In FIG. **4,** transverse annular rings or partitions **302,** 304, 306, 308, 310, and **312** are shown as mounted between the outer wall surface of the duct **266** and the inner wall surface of the outer skin **286.** The partitions or transverse bulkheads **302, 304, 306, 308, 310,** and **312** define the previously-mentioned compartments for receiving and housing the various missile component systems, as previously pointed out.

The inner edge of the annular rings or partitions are preferably welded to the missile duct **266,** while the outer skin **286** of the missile **100** is made of semiannular covers of lengths corresponding to the lengths between the bulkhead rings or partitions. The covers comprising the outer skin **286** of the missile **100** are preferably attached to the bulkhead rings or partitions by means of screws or the like. This makes it possible to have ready access to any missile component system, by simply removing the particular cover that encloses the system.

As previously indicated, wings **112, 113, 114,** and **115,** FIGS. **1, 2, 43B,** and **43C** are considered as part of the airframe structure. With the exception of the mounting details, the structure of each wing is substantially according to conventional aircraft practices. All four wings are identical in construction.

Each wing has a high aspect ratio and tip rake, which tends to minimize hinge moment variations with Mach number under various combinations of wing deflection and missile angle of attack with the tapered planform of each wing tending to minimize the bending moments. The biconvex cross sectional shape of the wings minimizes drag for a given strength, simplicity of manufacture, resistance to chordwise bending, and elimination of corners which can affect aerodynamic properties.

As illustrated in FIGS. **1**, **2**, **43B**, and **43C**, the four steering wings **112**, **113**, **114**, and **115** are oriented in a cruciform configuration and are located substantially near the center of gravity of the missile **100**. These wings **112**, **113**, **114**, and **115** are positioned in line with fins **116**, **117**, **118**, and **119**, respectively. The wings and fins are located substantially 45° to the transverse axes of the missile **100**.

Each wing **112**, **113**, **114**, and **115** includes a main spar **301** with a plurality of ribs **303** spaced spanwise, as seen in FIG. **43B**. Ribs **303** have fore and aft edges connected by leading and trailing edges **305** and **307**, respectively. The entire wing structure is covered by skin **309**, FIG. **43B**.

In FIGS. **22**, **23**, **24**, and **25**, there is shown a typical wing **112** which has, at its root or inboard end, fore and aft rib members **311** and **313**, respectively. Each root rib member **311** and **313** has an offset central portion **314** and an enlarged end portion **315**. The enlarged end portion **315** of each rib member **311** and **313** is received between two brackets **316** and **317** which are formed integrally with the main spar **301**. Bolts **318** and **319** are used to secure the enlarged portion **315** and the central portion **314** of each rib member **311** and **313**, respectively, to brackets **316** and **317** on wing spar **301**.

As illustrated in FIGS. **22** and **25**, a wing mounting bulkhead **310** is mounted between the outer missile skin **286** and the diffuser **270**. This bulkhead **310** is designed to receive a wing retaining sleeve **341**. The root end **343** of the spar **301** is inserted in the sleeve **341**. Roller bearings **321** and **325** of the needle type are located between the bulkhead **310** and sleeve **341** in order that the sleeve can be rotated in the bulkhead **310**.

A rectangular shaped slot **327** is provided in the bulkhead **310** for receiving a wing actuating crank **329** which fits about the wing retaining sleeve **341** and which is locked thereto by means of threaded taper pin screws **331**. The crank **329** has its driven end **333** slotted for receiving the piston rod **1386** from one of the wing actuators **1382** through **1385** as illustrated in FIGS. **20** and **21**. A bolt **1388** is utilized to secure the end of the piston rod **1386** to the wing crank **329**.

Wedged shaped tongues **335** are formed integral with the outer end of the wing retaining sleeve **341**, and are spaced from the outer skin **286** of the missile **100**. These tongues **335** are utilized to secure tapered end **337** of latch levers **339** in position so as to lock or secure wing **112** to the body of the missile **100**. Each tongue **335** has a tapered aperture **345** for receiving the tapered end **347** of bolts **318**, which, are used to secure the root rib members **311** and **313** to the wing spar **301**.

As shown in FIGS. **22**, **23**, and **24**, the latch lever **339** has a latch lever pivot boss **349** formed integral therewith at its end **337**. This pivot boss **349** is comprised of an enlarged cylindrical portion **351**, which is located in an aperture provided in bracket **317** adjacent to the end **337** of the latch lever **339**, a conical-cylindrical central portion **353**, a flange portion **355** which is received in a cylindrical recess **357** in the root rib members **311** and **313**, and a reduced cylindrical end portion **359** which is inserted in an aperture **361** provided in the root rib members **311** and **313** and the bracket **316**.

This pivot boss **349** is biased outwardly by means of a leaf spring stack assembly **363** as shown in FIGS. **22**, **23**, and **24**. The spring stack assemblies **363** are secured to each root rib member **311** or **313** by bolts **365** and **367**. End **369** of the longest leaf of spring assembly **363** has a U-shaped notch **371** provided therein. The notched end **369** of the spring assembly **363** is inserted between the flange **355** and conical-cylindrical portion **353** of the pivot boss **349**. When the end **337** of the latch lever **339** is placed between the wedged portion **335** of the wing retaining sleeve **341** and the outer skin **286** of the missile **100**, the leaf spring assembly **363** biases the flange portion **355** of the pivot boss **349** upwardly to jam the tapered end **337** of latch lever **339** under the tongue **335** of sleeve **341**, thus pulling the wing **112** inboard and firmly seating the tapered end **347** of bolts **318** in the aperture **345** effecting thereby an extremely secure mount of the wing **112** to the missile **100**.

The free end of the latch lever **339** is locked in its closed position by a latch lever catch **373** which is pivotally mounted on a screw **375**. Screw **375**, in turn, is secured to the root rib member **311** or **313**. The latch lever catch **373** has a flange portion **377** formed integral therewith. One end of the flange portion **377** forms a lip **379**, and is arranged to engage a notch **381** formed in the free end of latch lever **339**, while the other end **382** is offset to underlie a portion of the wing skin **309** when the latch lever **339** is in a latched position.

A spring **383** is utilized to bias the latch lever catch **373** outwardly in order to secure the latch lever **339** in a latched position. One end of the spring is inserted in an aperture **491** provided in a tongue portion **385** of the latch lever catch **373**, while the other end is secured to a pin **387**. This pin **387**, in turn, is secured to the root rib **311** or **313**.

As previously mentioned, when the wing **112** is assembled to the missile **100**, end **337** of each latch lever **339** is wedged beneath the tapered tongues **335** of the wing retaining sleeve **341**. The other (notched) end of each latch lever **339** is secured against rotation by the lip **379** on flange **377** and a latch stop **389** formed integrally on the latch lever catch **373**. When it is desired to remove the wing, or wings from the missile **100**, the flange **377** of the latch lever catch **373** is pressed inwardly against the spring **383**, FIG. **24**, thereby rotating the lip **379** out of engagement with notch **381**, and simultaneously bringing the tongue **385** into contact with the back side of latch lever **339** to kick the latch lever into the "unlatched" position.

As illustrated in FIGS. **15** and **25**, each wing, such as wing **112**, is provided with a wing lock **140** to prevent premature rotation of the wings. The winglock **140** is mounted on a winglock mounting beam or bracket **142**. This beam is located between the bulkheads **308** and

310, and has its ends secured to clip members **391**, which, in turn, are affixed to the bulkheads **308** and **310** by rivets **393**.

Each winglock **140** comprises a housing having located therein a piston (not shown) which is actuated by hydraulic fluid applied through the tube **395**. The piston drives a rod **397**, one end **399** of which is received in a recess **401** provided in rib member **311** of the wing **112** to lock the wing against rotation. When it is desired to release the wing **112** hydraulic pressure is applied to the piston through tube **395** to retract the pin **397** from the recess **401** in member **311**. The winglock **140** can be manually operated by inserting the end of a suitable tool through openings **403** and **405** provided in the missile outer skin **286** and beam **142**, respectively, to engage a notch **407** provided in a release latch **409**. The release latch **409** is provided with pawl **411** which engages a notch **413** in rod **397**. The release latch **409** is pivotally mounted, by pin **415**, to two brackets **416** which, in turn, are integrally secured to the winglock **140**. A spring **417**, having one end thereof connected to pin **415** and its other end resting against a pin **418** mounted on the release catch **409**, is utilized to bias the release latch **409**. By applying a force, in a clockwise direction, to the release latch **409**, it is pivoted in a clockwise direction about the pivot pin **415** to withdraw the rod **397** from the recess **401** in rib **311** to release the wing **112**.

All four tail fins **116, 117, 118** and **119** are alike with the exception that fins **116** and **118** carry the telemetering notch antennae **178**, and fins **117** and **119** are provided with tracking flare holders **180**.

As shown in FIG. **38**, each tail fin **116, 117, 118**, and **119** is constructed according to conventional practices and is comprised of leading and trailing edge members **419** and **421**, respectively, two spars **423** and **425**, a plurality of rib members **427** spaced spanwise of the fin, doublers **429**, and fore and aft root end ribs **431** and **433**, respectively. Each tail fin has an identical biconvex or double circular arc cross section for the same reasons as the wings **112, 113, 114**, and **115**. The entire tail fin structure is covered by skin **435**. The mounting structures for the four fins are identical in construction.

As illustrated in FIGS. **37, 38**, and **39**, four mounting rings **437** are provided between the wall **284** of the tailpipe **168** and a fairing **439** for supporting the four fin supports **170**. These fin supports **170** are utilized for attaching the tail fins to the missile **100**. Each fin support **170** has four arc shaped members **441**, FIG. **39** formed integral therewith, two at each end thereof for securing the fin support **170** to the fin mounting rings, by suitable means, such as rivets **443** and bolts **445**.

Each fin support **170**, is comprised of a body which is rectangular in cross section and which is arranged to be inserted into a rectangular shaped recess **447** provided in the root end of each fin. Holes **451** and **453** are provided in the fin support body for receiving pins **455** and **457**, respectively, which are formed integrally with the fin attachment device **176**. The fin attachment device **176** is sandwiched between the doublers **429** and the skin **435** of the fin. The fin attachment device is arranged in the fin so as to allow the pins **455** and **457** to protrude from the base of the rectangular shaped recess **447** in the fin.

The body of each fin support **170** has an aperture **459** provided therein for receiving a latching mechanism **461** which is utilized to secure the fin **116** to the fin support **170** on the missile. The aperture **459** is counterbored at **463** to receive a coil spring **465**.

A latching piston **467** is located in the aperture **459**. This piston **467** has a core **469** with a lip **471** formed therein. The coil spring **465**, in counterbore **463**, is used to bias the piston **467** into a locked position.

A plate **473** is secured to one end of the piston **467** by a screw **475**. This plate **473** maintains the piston **467** in the aperture **459** when the fin **116** is not secured to the fin support **170**. This plate **473** is received in a small recess **477** in the fin support **170**.

The fin attachment device or fitting **176** carries between its two pins **455** and **457** a headed lug **479** which cooperates with the lip **471** in core **469** of the piston **467** to securely lock the fin **116** in place after installation on the missile **100**. The head **481** of the lug **479** is tapered to facilitate its insertion into the core **469** of piston **467**. The piston **467** is held against rotation in the aperture **459** by means of a pin **483** press fitted into a hole in the fin support **170**. This pin **483** slidably engages a slot **485** milled in the surface of the piston **467**.

In operation, when the fin is assembled to the fin support **170**, the pins **455** and **457** are inserted in their holes **451** and **453**, respectively, and the lug **479** is inserted into the fin support **170** through an aperture **487** provided in the fin support. The tapered head **481** of the lug **479** rides against the sloping face **489** of the lip **471**, forcing the piston **467** to the left, until the head **481** of lug **479** enters the core **469** allowing the spring **465** to pull the lip **471** into locking engagement under the head **481** of lug **479**.

The fin can be removed from the fin support **170** by pushing the piston **467** to the left to withdraw the lip **471** from beneath the head **481** of the lug **479**, and then withdrawing the pins **455** and **457**, and lug **479** from their cooperating apertures in the body of the fin support **170**.

The overall propulsion system for the missile **100** includes the booster **500** for projecting the missile to the desired separation velocity for operation of the ramjet engine, and the ramjet engine for accelerating the missile **100** from the booster-missile separation velocity to its design velocity where the velocity of the missile **100** is then stabilized by the missile fuel control system **230**. The propulsion system includes the aforementioned missile fuel system including the fuel tank **138**, the fuel pressurization system **228**, and the fuel control system **230**.

The ramjet engine for the missile **100** is designed to accelerate the missile **100** from the velocity that the missile **100** has at the time of its separation from the booster rocket **500** to its design velocity. The velocity of the missile **100** is then controlled by the fuel control system **230**, as previously pointed out. In general, the ramjet engine includes the single oblique shock, spike diffuser **270**, the piloted can combustor **108** and the convergent-divergent exit nozzle **172**.

In this missile **100**, at the design speed, the supersonic air stream passes through the oblique shock wave which is centered at the nose of the inner body **120** of the missile **100**. In passing through this shock wave, the velocity of the air stream is decreased to a lower supersonic velocity. At the entrance **268** of the diffuser **270**, the air stream passes through a normal shock wave and its velocity is then reduced in the first stage (short conical section) **278** of the subsonic diffuser to a high subsonic velocity. The air is then expanded in the second stage (intermediate cylindrical section) **280** of the subsonic diffuser **270** to a lower subsonic velocity. Since an increase in pressure in the diffuser **270** is associated with a decrease in velocity therein, the pressure in the diffuser **270** is increased. The air is then mixed with the fuel and is burned continuously in the combustor **108.** This maintains the high pressure in the diffuser **270** and also increases the volume of the air by increasing its temperature in the combustor **108.**

The thrust developed by the missile ram engine is, therefore, equal in magnitude to the difference of momentum between the incoming air and the outgoing products of combustion as best seen from Equation (2) below:

$$T = [(M + m)v_2 - Mv_1\ ] \qquad \text{Eq. (2).}$$

where

T = thrust force in pounds;

M = mass flow of air in slugs per second;

m = mass flow of fuel in slugs per second;

v_1 = incoming velocity of air in feet per second; and

v_2 = outgoing velocity of products of combustion in feet per second.

FIG. **92** illustrates diagrammatically the ramjet engine for the missile **100.** It has a multiple shock diffuser **270** to slow the incoming air and convert the velocity energy to pressure energy. It is composed of the inner body **120** and the aerodynamic (inner) duct **266.** The multiple shock diffuser **270,** with the projecting inner body **120** forming shock waves at the diffuser entrance, reduces the velocity in easy stages through one or more angle shock steps before it reaches the final weak normal shock that drops the velocity to a subsonic value. The normal shock, in this case is much less severe than one across an open duct. Using this method, therefore, more ram pressure can be recovered and put to use.

Assuming that the ramjet engine has been boosted to a Mach number M = 1.7, a cycle through the engine will be followed by reference to FIGS. **92, 93, 94** and **95.** At point **1,** ambient conditions exist. At point **2,** the first angle shock is formed by the projecting inner body **120.** It has been found that as air flows through a shock wave, the pressure increases abruptly, the velocity decreases, and the temperature increases. Point **2** on the three curves in FIGS. **93, 94** and **95** shows these changes. Between points **2** and **3,** the air has been slowed to a velocity somewhat less than M = 1.7. At point **3,** a second, weaker angle shock wave is formed. As the air passes through the shock wave, the same type of changes take place (see point **3** on the curves). Between points **3** and **4,** the air has a velocity less than between points **2** and **3,** but still greater than M = 1.0. At point **4,** the weak normal shock wave is formed. This also causes the same type of changes and finally drops the airflow to subsonic conditions. From this point on, the airflow greatly benefits from the law of continuity (the mass flow (ρ AV) = a constant) and Bernoulli's theorem (as the velocity decreases, the pressure increases). By the law of continuity, as the area of the diffuser **270** increases, the velocity decreases to keep the mass flow constant. Since the velocity constantly decreases, the pressure increases.

Leaving the diffuser **270,** the air flows into the combustor chamber **272.** The correct balance between the combustion chamber pressure and the diffuser exit pressure is quite critical for the proper operation of the ramjet engine. If the combustion chamber pressure is too high, the diffuser pressure will be too high and will tend to push all the shock waves upstream slightly, detaching the first angle shock wave. This will cause "spillover" which effectively diverts some of the incoming air that is needed for the proper operation of the engine. If the combustion chamber pressure is too low, the diffuser pressure will also be too low and the shock waves will all be moved downstream slightly, the first angle shock wave being swallowed. With this condition existing, large pressure losses, turbulence, and heat generation occur, thereby lowering the efficiency of the engine.

Assuming now that the correct combustion chamber pressure exists, the following action takes place. The air from the diffuser **270** is mixed with fuel, the mixture is ignited and burned. The increases in temperature increases the volume of the air mass. The hot expanding gases try to find an exit, but are blocked radially by the walls and upstream by the diffuser pressure. Because of this flow restriction, the diffuser pressure increases and forces the combustion gases out the rear exit at a very high velocity. The increased diffuser pressure is transmitted upstream to the incoming air. This action allows the incoming gases to remain compressed, for without this back pressure the pressure in the diffuser would not be maintained.

The ramjet missile **100** is pushed along in aerial flight by two natural occurrences, namely the high diffuser pressure created by the forward motion and that of the hot gases formed by combustion; and the fact that pressure is exerted equally in all directions and acts perpendicular to a surface.

As shown in FIG. **96,** pressure acts normal to the diffuser walls and the inner body **120.** However, each pressure force can be broken into two force components, one acting laterally (perpendicular to the engine axis) and one acting longitudinally (parallel to the engine axis). All the lateral force components cancel out, eliminating any unbalance in the lateral direction. All the longitudinal force components act in the same direction, and when summed up, equal the output thrust from the ramjet engine, a force which is large enough to stabilize or accelerate the engine at the designed supersonic speeds.

The chosen trajectory for the missile **100** is determined by the altitude and range of the target with the consumption of fuel being the criteria for the chosen path of travel of the missile **100.** At high altitudes, the drag and air mass intake to the ramjet engine are low. Since the thrust developed by the ramjet engine is dependent upon the air-fuel ratio in the combustor **108,** low fuel flow rates are needed for aerial flight of the missile **100** at high altitudes. For long range flights, an up-and-over trajectory will be used for the missile **100.** For shorter ranges, where fuel consumption is not critical and tie-up time of the radars is more important, a more direct path of flight of the missile **100** will be used. This is illustrated in FIG. **97.**

The multi-shock diffuser **270** is utilized to slow the incoming air and to convert its velocity energy to pressure energy. Fuel is then injected into the airstream passing through the missile **100,** and the air-fuel mixture is then introduced into the combustor **108.**

This combustor **108** is composed of two stages; namely, the pilot stage and the main stage. Each stage has its own fuel distribution system which supplies it with the proper air-fuel mixture to maintain combustion in the combustor **108.** The gases liberated due to the burning of the fuel escape through the exit nozzle **172.**

The diffuser assembly is comprised of a Ferri type inlet designed for high pressure recovery with low additive drag over the design Mach number range, a cylindrical section, and a conical-cylindrical section which encloses the combustor pilot **320,** FIGS. **1** and **7.**

The diffuser assembly, in particular, comprises a single cone, Ferri type supersonic intake, which is followed by a two stage subsonic diffuser **270.** As indicated in FIG. **7,** this intake is comprised of the circular inlet **268** in the center of which is placed the streamlined inner body **120.**

This inner body **120** is supported by three strut members **322, 323,** and **324,** which are attached at one end to the inner body **120,** with the other ends thereof being attached in the inner wall of the conical section **278** of duct **266,** FIGS. **2** and **7.**

The distinctive feature of the inner body **120** is the conical nose **326,** which has an angle of approximately 22.75°, causing a single conical oblique shock wave which accounts for the external supersonic compression of the air before it enters the inlet **268** of ramjet missile **100.** In the vicinity of the cowl lip **276,** depending on the particular configuration, a normal shock wave occurs. These two shock waves complete the supersonic compression of the air.

In addition to supersonic compression of the air, the air undergoes two stages of subsonic compression in the subsonic diffuser **270** which includes the first cylindrical section **280,** the divergent or conical section **282,** and the second cylindrical section **284,** of the missile duct **266.** The first stage of subsonic compression of the air occurs in the duct between the cowl lip **276** and the exit **328** of the first cylindrical section **280** of the duct **266,** while the second stage of subsonic compression of the air occurs in the divergent section **282** and the second cylindrical section **284** of the duct **266.**

The combustor **108** of the ramjet engine is that part of the ramjet engine in which the fuel is injected and burned. One of the characteristics of the combustor **108** is that it delivers the heat value contained in the injected fuel to the air flowing through the combustor **108** with a high degree of efficiency and low aerodynamic drag. The combustor **108** is also capable of sustaining burning over a wide range of air flows. The combustor **108** was designed to occupy a minimum of space and a small fraction of the total weight of the missile **100.**

The speed and altitude requirements of the missile **100** determines that the combustor **108** be required to operate at pressures as low as 5 psia pressure (high altitude requirement), and that a minimum cruise combustion efficiency of 80 percent at high altitudes and 90 percent at low altitudes be obtained. Cruise thrust requirements for the missile **100** demanded fuel-to-air equivalence ratios ranging from 0.2 to 0.6 be used.

Referring now to FIGS. **31** through **36,** the pilot section **320** of the combustor **108** contains pilot fuel injectors **330,** pilot shrouds **332** and **334,** and an annular pilot combustor can or flameholder **336.** It is the function of this pilot section **320** to ignite and stabilize the burning of the main fuel and air mixture in the combustor **108.** Fuel for the pilot injectors **330** travels down a centrally located tube **164** from a pilot regulator **340** to four radially mounted pipes **342** which carry the fuel to the pilot fuel manifold **344** carried between the shrouds **332** and **334** forward of the pilot flameholder **336.** Air for the pilot section **320,** approximately **20** percent of air flow through the ramjet engine, is captured by an annulus **346** formed by the inner and outer pilot shrouds **332** and **334,** respectively, and located in the divergent section **282** of the diffuser duct **266.** The fuel is injected into the air stream from the manifold **344** by sixteen spring loaded pintle type injectors **330** which will be described later. Fuel is injected forward into the air stream (that is, in a direction contra to the direction of movement of the air stream) in a fine spray to insure thorough mixing with the air and rapid vaporization thereof.

As illustrated in FIGS. **31** and **33,** the air-fuel mixture then passes through apertures **348** in the walls **350** and **352** of the stainless steel pilot flameholder **336** to the inside of the pilot flameholder **336.** Once inside the pilot flameholder **336,** the air-fuel mixture burns by the flame holding on the incoming air jets. The velocity of the air-fuel mixture entering the apertures **348** is such that flashback and burning of the pilot walls **350** and **352** is prevented. Cooling louvers **354** are provided between the apertures **348** to prevent these areas from becoming overheated. The flame from the pilot flameholder **336** exhausts to the main burning area without restriction. At its forward end, the pilot flameholder **336** is supported in the combustor **108** by four slotted blocks **356** which cooperate with lugs **358** which are welded to struts **360.** Struts **360** are, in turn, bolted to four combustor supporting stringers **362** which are, in turn, riveted to the intermediate conical section **282** of the duct **266.** In order to provide for expansion and contraction of the parts due to heating and cooling, the after end of the pilot flameholder **336** is loosely supported by means of flanged rings **364** and **366.** Flanged ring **364** engages a channeled ring **368** on the combustor central can assembly **370** and ring **366** engages a cylindrical tongue **372** on the combustor cooling shroud assembly **374.**

The main combustor **376** for the missile **100** is comprised of a main fuel injector **378,** the combustor central can assembly **370,** the combustor cooling shroud assembly **374,** and the convergent-divergent exit nozzle **172.** The fuel for the main combustor **376** is transferred from a main fuel regulator **380** by the main fuel delivery tube **166,** which is supported concentrically within the pilot fuel delivery tube **164,** to a main fuel distribution valve **384** located at the forward end of the combustor central can assembly **370.** This valve **384** is a spring loaded sliding piston valve that has a maximum pressure drop of 30 psi. This fuel distribution valve **384** divides the fuel flow into sixteen equal parts and ditributes this fuel to each of sixteen main fuel injectors **386,** which will be described later.

These injectors **386** are equally spaced around the inside of the combustor central can assembly **370.** The forward end **388** of the central can assembly **370** is open to free flow of air from the diffuser **270,** and is of such size as to capture 60 percent of the air entering the combustor **108.**

The air, after mixing with the fuel, flows radially outward through the apertures **390** in the combustor central can assembly **370** into the main burning area, which is merely as extension of the exit of pilot flameholder **336**. All burning of the main air-fuel mixture takes place after passing through the apertures **390** in the combustor central can assembly **370** with the flame holding on the air jets entering the burning zone. The apertures **390** in the combustor central can assembly **370** provide sufficient cooling with the rsulst that louvers are unnecessary. The combustor central can assembly **370** is supported by four stringer-type hangers **392**. Hangers **392** are provided at their forward end with studs **394** which fasten to the four main support struts **360** of the combustor **108**.

As shown in FIGS. **31** and **36**, the combustor cooling shroud assembly **374** is located externally with respect to the burning zone in order to keep the tailpipe **168** cool by channeling air from the diffuser **270** between the tailpipe **168** and the combustor shroud assembly **374**. Approximately **20** percent of the air flow through the ramjet engine is used for cooling. The shroud assembly **374** itself is cooled by two rows of small apertures **396** and **398** at its forward end **400** and four rows of louvers **402** which direct relatively cool air over its inner surface **404**. This air does not have any fuel injected into it. The air, after passing through the cooling shroud assembly **374** through apertures **396** and **398**, and louvers **402**, mixes with the main air stream and aids in burning of the air-fuel mixture. A gap **406**, provided between the shroud **374** and the tailpipe **168**, permits a flow of cool air to pass over the exit surface of the nozzle **172**, thus cooling it to prevent burn out thereof.

In FIGS. **31** and **36**, the forward section **400** of the shroud **374** is supported in the combustor **108** by four pairs of lugs **408** which bolt to struts **360**, which are, in turn, bolted to stringers **362** in the combustor **108**. The aft section of the shroud assembly **374** is supported in the combustor **108** by a series of thin flat strutlike members **410** which are formed from continuous strips and welded to the outer surface of the shroud assembly **374**. The outermost webs **412** of struts **410** are capped by a strap **414** encircling the entire shroud assembly **374**.

Due to the limited space available for the combustor **108** in the missile **100**, it is necessary to insert the combustor pilot section **320** as far as possible into the exit of the diffuser **270**. Inserting the pilot section **320** into the diffuser exit aids in obtaining high combustion efficiencies.

A high degree of burning stability with high combustion efficiency has been achieved in the missile **100** by the use of a pilot section **320** with a large heat release (approximately 20 percent of the total air flow through the missile **100**) and the use of a nearly constant air-fuel ratio in the pilot stage of the combustor **108**. The durability of the combustor **108** is insured by the use of the cooling louvers **354** and **402**, and the shroud assemblies **332, 334, 336, 370,** and **374.**

At separation of the missile **100** and the booster rocket **500**, where the air loads on the combustor **108** are high, supersonic air flows (hence low pressures) may be present in parts of the combustor **108**, with high differential pressures across components. Since these parts have not been heated by burning, their strength will be a maximum and no damage will result.

The initial thrust for the missile **100** is supplied by the solid propellant booster rocket **500** which separates automatically at the end of the boost phase. At separation of the booster rocket **500** and missile **100**, the missile will be travelling at a Mach number where, after rapid ignition of the fuel takes place, sufficient thrust for acceleration will be produced by the ramjet engine. The missile **100** will accelerate to design velocity and then maintain this velocity through the remainder of the flight to an aerial target. To accomplish this, the missile **100** carries a fuel supply **138**, a fuel pressurization system **228**, fuel injectors **320** and **378**, a fuel control system **230**, and a combustor **108** necessary for operation as a ramjet engine.

In FIGS. **8, 9A, 9B, 26, 27, 28,** and **29**, there are shown the working components of the complete fuel system. The fuel control system **230** begins with the supply of the fuel from the fuel tank **138** and ends with the delivery of the correct amount of fuel to the pilot and main fuel ducts **420** and **422**, in an air intake strut **424**, which carry the fuel back to the pilot and main injectors **320** and **378**, respectively, of the combustor **108**.

The ramjet engine fuel is contained in an annular tank **138** which is provided with a quickdisconnect fuel filler valve **426**. An outlet line runs from this tank **138** to a "G" operated fuel shutoff valve **428** which holds the fuel in the tank **138** until the booster rocket **500** operation provides the necessary inertia force to trip a valve opening mechanism **430**. Provision is made for expansion of the fuel during storage in the fuel tank **138**.

Fuel is forced from the tank **138** and kept under pressure by means of two pressurized flexible bladders **438**, located in the tank **138**. This insures delivery of fuel to a fuel pump **440** at pressures sufficient to prevent cavitation of the pump under all flight conditions. The pressurization of the bladders **438** is obtained from a tank **442** of high pressure nitrogen and is controlled by a two stage nitrogen flow control or regulator unit **444**. This unit **444** also contains a boost inertia force tripping G valve **446** and a surge-preventative piston valve **448**.

In low altitude flight, the nitrogen supply is rapidly used up and an alternate pressurizing source incorporating pressurized air from the diffuser **270** is utilized to pressurize the fuel in the tank **138**. The alternate pressure source is utilized when the regulated nitrogen pressure drops below the inlet air pressure of the turbine pump **440** (diffuser pressure minus scoop losses), whereupon a check valve **450** opens and the diffuser air pressure then supplies the pressurization for the bladders **438** in the fuel tank **138**.

A safety relief valve **452** is incorporated in the nitrogen pressurizing system and referenced to the pressure in the diffuser **270** to limit the pressure across the inner wall **454** of the fuel tank **138**, which is the limiting portion of the structure of the fuel tank **138**.

The turbine driven fuel pump **440** is utilized for pressurization of the fuel. This turbine is a single stage impulse type with supersonic nozzles **456**. The turbine fuel pump **440** is of the single stage centrifugal type. The turbine fuel pump **440** maintains an outlet pressure above the minimum required for fuel flow control. This pressure is dissipated in line losses, strainer loss, regulator drop and injector drop, plus diffuser pressure. The pilot and main fuel regulators **340** and **380**, respectively, require a certain throttling pressure drop to operate and are capable of throttling considerably more than this. The excess pump outlet pressure is then throttled by these regulators **340** and **380**, with the result that a reserve of pressurized fuel is thus provided to take care of varying demands and also to provide a margin of safety.

The sliding parts of the fuel regulators **340** and **380**, and injectors **330** and **386** are of precision construction with clearances requiring dirt free operation. A fuel strainer **458** removes all contaminating materials of sufficient size to cause binding of the sliding parts. As the fuel leaves the strainer **458**, it is divided into two streams to supply clean fuel to both the pilot and main regulators **340** and **380**.

The pilot regulator **340** controls the fuel flow rate to the pilot section **320** of the combustor **108**, maintaining a nearly constant air-fuel ratio which insures stable combustion at all times. The main regulator **380**, on the other hand, controls the fuel flow rate to the main section **376** of the combustor **108**. The main regulator **380** incorporates a velocity control mechanism which causes a shift in fuel flow from a rich limit to a lean limit in the design velocity range. The rich limit operation will produce sufficient thrust to give acceleration of the missile **100**, while lean limit operation, which will be nearly zero flow through the main regulator **380**, will result in deceleration of the missile **100**. This will give a constant velocity of the missile **100** at some flow between the rich and the lean limits.

Fuel flowmeters **460** and **462** are provided at the outlets of both regulators **340** and **380**, respectively, for measurement of fuel flow through the pilot and main systems.

The fuel storage tank **128**, is annular in shape and contains the supply of fuel, preferably kerosene, necessary for operation of the ramjet engine of the missile **100**.

The fuel storage tank **138** is located in the fuel tank compartment **222** which occupies a section of the missile **100** beginning at approximately mid-chord of wings **112**, **113**, **114**, and **115**. It is an integral part of the missile airframe, and is formed by the outer surface **464** of the diffuser of duct wall **274** reinforced by five stiffening rings **466** and the inner surface of the missile skin **286**. Both the missile skin **286** and the diffuser wall **274** are made of stainless steel in this region. The ends of the tank **138** are formed by annular stainless steel rings or bulkheads **468** and **470**, hemispherical in cross section, welded to the missile outer skin **286** and the diffuser wall **274**. The tank is fitted with a fuel drain plug **472** on the bottom and has an air vet plug **474** provided in the top thereof.

As shown in FIGS. **26**, **28**, **29**, and **30**, the tank **138** contains two longitudinal partitions **476** and **478** to separate the two bladders **438**. The partitions **476** and **478** are constructed so as to form perforated triangular longitudinal fuel feeder channels **480** and **482**. Welded to the end walls **468** and **470** are perforated conical rings **484** and **486**, respectively, which cooperate with said end walls to form annular fuel feeder channels **488** and **490**. Two perforated gusset plates **492** are provided at the intersection of longitudinal feeder channel **482** and annular feeder channel **488** so as to form a fuel collection area **494**. Thus, all fuel feeder channels are in communication with the fuel collection area **494** permitting fuel in any part of the tank **138** to reach the fuel outlet **436**.

The tank **138** contains two access doors **496** for installation of the bladders **438**. These doors **496** are secured in place by machine screws and sealed against leakage by an "O" ring around their inner surfaces. The forward bulkhead **468** of the tank **138** is fitted with two bosses **498** through which the fittings for the tank bladders **438** pass and connect with nitrogen pressurization lines **502**.

Bladder fittings **504** are held in the tank boss **498** by lock nuts **506**. An effective nitrogen seal at the bladder fittings **504** is achieved by clamping the bladder **438** between the head **508** of the fitting **504** and a washer **510**. A conventional gasket **512** between the tank boss **498** and the washer **510** provides a simple fuel seal. Other bosses **514** and **516**, as shown in FIG. 9B, in the forward bulkhead **468** are provided for connecting the fuel line **436** to the fuel shut-off valve **428** and to vent the fuel line **436** to the inlet side of the fuel shutoff valve **428** back to the tank **138**.

The 2 ¼ inch aluminum fuel line **436** is connected to the tank boss **514** by a short flexible hose **518** which is secured by clamps **520**. A boss **521** located in the aft tank bulkhead **470** connects the tank **138** to the fuel fill port valve **426** which is utilized to fill the tank **138** with fuel through an internal tube fitting (not shown). This port valve **426** is a quick disconnect fitting that is self-closing when the external fuel fill line (not shown) is disconnected. The tank **138** is an integral part of the missile airframe, and is a load bearing part of the missile **100** in aerial flight.

The missile fuel tank **138** contains two, two-ply nylon fabric, neoprene-impregnated bladders **438**. Each bladder **438**, when fully inflated, occupies approximately one-half of the missile tank volume. The bladders **438** are installed in the fuel tank **138** through the access doors **496** and are held securely in place by the bladder fittings **504** and by a plurality of snap fasteners **522** which lock in holes **524** that are provided in the longitudinal feeder channels **480** and **482**. To facilitate easy installation and to minimize the number of openings on the bladders, each bladder **438** has bonded to it two longitudinal tongues **526**, the free ends of which are provided with a series of snap fastener holes corresponding to the number of snap fastener holes **524** in the longitudinal feeder channels **480** and **482**. The bladders **438** conform to the inside shape of the tank **138** when fully inflated, and are completely supported by the tank walls, ends, and partitions except for the spaces where the holes are drilled in the partitions and conical plates for fuel passage.

When the missile **100** is in fueling position, a vent line **432** is provided from the top of the fuel shut-off valve inlet **434** to the top section of the fuel tank **138** to eliminate any trapped air from a high spot which exists at the inlet of the fuel shut-off valve **428** and to insure complete fuel charging of the tank **138**.

In FIGS. 9A and 9B, the fuel in the tank **138** is pressurized, from two sources, namely the inert gas tank **442** or, scoop **772** which extracts diffuser pressure from the missile duct **266** when the nitrogen pressure drops below the pressure in the diffuser **270**. The diffuser pressure is then supplied to the bladder **438** through a line **528**, check valve **450**, a line **530**, and line **502**. Fuel pressurization is necessary in order to provide fuel at the inlet **532** of the fuel pump **440** at sufficient pressure to prevent cavitation of the pump, to provide sufficient fuel pressure at high altitudes, and to eliminate boiling of the fuel in the fuel tank **138**. The minimum pump inlet pressure required to prevent cavitation of the pump **440** depends upon the volume of fuel flow, fuel vapor pressure (fuel temperature), and, to a small extent, missile accelerations.

When the fuel is pressurized by the inert gas pressurization system, which utilizes the gas, such as nitrogen, the gas is supplied from the nitrogen tank **442** which is provided with two hemispherical ends **534** and **536** and the body **538.** End **534** of the tank **442** is fitted with a boss **540** for a clean-out plug which is sealed by an O ring. Near the opposite end **536** of the tank **442,** a fitting **542** is affixed to the tank body **538.** A tube **544** is connected to the fitting **542,** and to the nitrogen flow unit **444.**

The nitrogen tank **442** is filled by a tire type fill valve **546,** as seen in FIGS. **9B** and **27,** which is attached to a fill and gauge manifold **548.** This valve **546** incorporates a secondary metal-to-metal sealing seat to reduce leakage of the nitrogen. A pressure gauge **550** is mounted in the filler and gauge manifold **548** to give a visible indication of the charging pressure in the nitrogen tank **442.**

The fuel control system, as indicated above, incorporates the fuel pressurization bladders **438** in the fuel tank **138.** Each bladder **438,** external of the tank **138,** is, in turn, connected to the line **544** supplying the inflation nitrogen pressure from the nitrogen tank **442.**

When fully extended, the bladders **438** are supported by the walls of the fuel tank **138,** except for a considerable number of holes in the various members **476, 478,** 484, and **486** in the fuel tank structure. The bladders **438** conform to the hat shape stiffener rings **466** in the fuel tank interior and are held in place longitudinally, by the hinge type flaps or tongues **526** which are fastened to the fuel feeder channels **480** and **482** with snap fasteners **522.**

A quick disconnect bleeder valve **552** is provided in the pressurizing line **502** to vent the bladders **438** and permit them to collapse during the fueling process.

The nitrogen flow control unit **444,** as best seen in detail in FIG. **14,** is provided to supply the nitrogen at a pressure equal to ram pressure plus **28** psi to the fuel pressurization bladders **438** and to prevent leakage of high pressure nitrogen during storage thereof. When the pressure of the nitrogen dorps below that of the pressure of the diffuser **270,** the check valve **450** opens and the fuel tank bladders **438** are then pressurized by the larger pressure of the diffuser **270.**

It has been determined that the nitrogen must be supplied at the pressure indicated based on the fuel flows required in the missile **100** and the fuel tank size, minimum fuel pump inlet pressures to prevent cavitation, acceleration effects of the missile **100** on pump inlet pressures, and fuel vapor pressure variation with fuel temperature. The flow control unit **444** is sealed against nitrogen leakage by the use of O rings and leather gaskets. The pressure from the nitrogen tank is applied through tubing **544** to the inlet **562** of the surge preventing valve assembly **448.**

The surge preventing valve assembly **448** is comprised of a sleeve **564** secured in the body casting **560** by a steel snap ring **566.** Four ports **568** permit the nitrogen to flow from the center of the sleeve to an annulus **570** around the sleeve **564.** This annulus **570** leads to the inlet **572** of the shut-off valve **446.** Piston **449,** which prevents surge of the nitrogen, fits inside of the sleeve **564.** The inlet end **574** of the piston **449** has four V-shaped slots **576** cut into it. The opposite end **578** of the piston **449** is closed, and is fitted with a flange **580** to position it in the closed position.

A spring **582,** compressed between a piston stop **584** and the top **578** of the piston **449,** holds the piston **449** in the closed position when no nitrogen is flowing. The piston stop **584** is threaded for purposes of adjustment and is locked in place by screw **586.** a boss **588** on the stop **584** limits the travel of the piston **449** and also maintains the spring **582** in a central position.

The cover **590** for the surge preventing valve assembly **448** is screwed into the main body casting **560** and is sealed by an O ring **592.** The space between the top of the piston **578** and the piston stop **584** is connected to the shut-off valve inlet passage **572** by a drilled passage **594** fitted with a No. 80 bleed **596.**

When the nitrogen tank **442** is charged, with the nitrogen shut-off valve **446** closed, nitrogen tank pressure is applied to both sides of the surge preventing piston **449** by leakage past the piston **449.** When the nitrogen shut-off valve **446** is opened, a sudden decrease in pressure on the surge preventing valve outlet **598** causes the valve **448** to open.

However, the high pressure nitrogen on the back side of the piston **449,** bleeding off through the No. **80** bleed **596,** causes the valve **448** to open slowly, and prevents a surge of high pressure nitrogen from passing through the flow control unit **444.** The spring **582** tending to close the piston **449** causes a small pressure drop to be generated across the surge preventing valve **448.**

The outlet port **598** of the surge preventing valve **448** is directly connected to the inlet **572** of the nitrogen shut-off valve **446.** This valve **446** is of the inertia activated type. It opens during launching of the missile **100.** The shut-off valve **446** is locked in the closed position by six stainless steel balls **600** which ride in a groove **602** on the valve stem sleeve **604.** When the valve is open, it is locked in the open position by the same steel balls **600.**

The nitrogen shut-off valve **446** consists of a valve disc **606,** a valve seat **608,** a valve stem **610,** thc previously mentioned valve stem sleeve **604,** a ball retaining sleeve **612,** a G weight **614,** a shut-off valve cover **616,** two springs **618** and **620,** the six steel balls, **600,** and various O rings and gaskets. The six steel balls **600** fit into holes **622** drilled through the ball retaining sleeve **612,** and project into the groove **602** machined on the valve stem sleeve **604.** The ball retaining sleeve **612,** at the point where the ball retaining holes **622** are drilled, is slightly thicker than one-half the diameter of the balls **600.** The groove **602** in the valve stem sleeve **604** is slightly less than one-half the ball diameter.

The G weight **614** is held down over the balls **600,** forcing them into the groove **602** in the valve stem sleeve **604,** by the spring **618** mounted between the weight **614** and the shut-off valve cover **616.** The valve stem **610** is threaded into the valve stem sleeve **604,** and is provided with a knurled thumb screw **624** at the end. The valve stem sleeve **604** is spring loaded towards the open position by the spring **620** between the valve stem sleeve **604** and the ball retaining sleeve **612.**

When the valve stem **610** is screwed into the valve stem sleeve **604,** the valve disc **606** is seated on the seat **608.** A force is applied to the balls **600** between the valve stem sleeve **604** and the ball retaining sleeve **612,** locking the valve **446** in place. The balls **600** are held in position by the tapering inside diameter of the acceleration actuated weight **614** which fits over them.

The weight **614** is held in place by the precision spring **618.** During launching, when the missile acceleration reaches between **5** and **12** g's, the G weight **614** moves against the pressure of the spring **618** to compress it to a position where the larger inside diameter of the weight **614** allows sufficient relief space for the balls **600** to move outward into the larger diameter machined on the inside of the weight **614.** This movement of the six balls **600** releases the valve stem sleeve **604,** from the groove **602,** allowing the valve stem spring **620** and the high pressure gas on the bottom of the valve disc **606** to open the valve **446.**

When the boost phase of the missile **100** is over, the G weight spring **618** moves the weight **614** back to its original position, forcing the balls **600** into a second groove **626** machined on the valve stem sleeve **604,** thus locking the shut-off valve **446** in the open position. The valve **446** is sealed against leakage in the open position by an O ring **628** fitted into a groove **630** on the back face of a valve disc cap **632.**

The valve seat **608** is an insert with a lip **634** machined on one surface **636** thereof. This lip **634** is positioned to mate with the valve disc **606.** The valve seat **608** is secured in place with machine screws **638,** and it is sealed with an O ring **640.**

The valve disc **606** comprises a cup **642** and a cap **632,** which are screwed together and locked by a lock washer **644.** The cup **642** contains a resilient washer insert **647** which mates with the lip **634** machined into the valve seat **608** to seal against the high pressure gas applied to the bottom of the disc **606.** The cap **632** of the valve disc **606** is fitted with the O ring **628** to seal against gas leakage past the valve stem **610** when the valve **446** is open.

A collar **646** is held between the cap **632** and cup **642** of the valve disc **606,** and it is screwed and pinned to the valve stem **610.** The shock absorbing washer or gasket **648** is sandwiched between the collar **646** and the cap **632.** When the valve **446** is opened, the valve disc **606** moves up into the ball retaining sleeve **612,** with the O ring **628** sealing against the valve disc cap **632** and the ball retaining sleeve **612.** The hard rubber shock absorbing gasket **648** prevents excessive shock on opening of the valve from breaking the valve stem **610.**

Pressure regulation by the flow control unit **444** is carried out by two nearly identical pressure regulation stages **650** and **652.** Each pressure regulation stage **650** or **652** consists of a reference chamber **654** or **656** containing a spring **658** or **660,** a regulating piston **662** or **664** containing ports **666** or **668,** a ported piston sleeve **670** or **672** and a damping piston assembly **674** or **676,** respectively. The outlet **678** of the nitrogen shutoff valve **446** is directly connected to an annulus **680** surrounding the first stage pressure regulating piston sleeve **670.**

This sleeve **670** contains four ports **682,** that are aligned with four triangular ports **666,** cut through the regulating piston **662.** The regulating piston **662** is held in the open position in the sleeve **670** by means of the **30** pound spring **658** mounted in the reference chamber **654.** The second stage regulator outlet pressure is also applied to the first stage regulator reference chamber **654,** by means of a bleed **651.**

A damping piston **684** is inserted into the inside of the regulating piston **662.** The damping piston **684** is held in a fixed position by means of a tie rod **686** securing it to the flow control unit body **560.** When high pressure nitrogen from the shut-off valve **446** is applied to the first stage **650** of the pressure regulator **444,** the regulating ports **666** in the piston **662** are open. Nitrogen passes through the ports **682** in the piston sleeve **670** and the ports **666** in the piston **662** to the inside of the piston **662.** Nitrogen leakage past the damping piston **684** applies the first stage regulated pressure to the space between the top of the damping piston **684** and the closed end **688** of the regulating piston **662.**

When the pressure applied to the inside end **688** of the regulating piston **662** exceeds that applied in the opposite direction by the reference chamber **654** and the spring **658,** the piston **662** moves in such a manner as to close the ports **666** in the piston **662** and keep the total force applied to the top **688** of the piston **662** equal to that applied to the bottom of the piston **662.** The spring **658** mounted in the reference chamber **654** acts over an area of approximately one-third square inch. Thus, the first stage regulator outlet pressure is approximately 100 psi higher than the outlet pressure of the flow control unit **444.** The damping piston assemblies **674** and **676** are included in the unit **444** to damp out rapid pressure fluctuations on the bottom side of the pistons **662** and **664,** and give a smoother outlet pressure.

The first outlet pressure of the first regulation stage **650** is applied directly to the inlet **690** of the second pressure regulating stage **652.** The second pressure regulation stage **652** of the flow control unit **444** is identical to the first with the following exceptions noted below. The reference chamber **656** is vented to ram pressure and contains an accurate spring **660** that can be adjusted, and the walls of the piston **664** of the second pressure regulator stage **652** are thinner than in the first pressure regulation stage **650.** As the spring **660** in the second pressure regulation state **652** acts over an area of slightly less than one-third square inch, the flow control unit outlet pressure is **28** psi above ram pressure.

The nitrogen flow control unit outlet **692** is connected to tubing **694** which leads to the relief valve **452** and bladders **438.** A tubing fitting (not shown) also connects the flow control unit outlet **692** to the bladder vent fitting **552.** This fitting is of the quick disconnect type which bleeds the bladders **438** to atmospheric pressure when installed. This vent **552** is fitted with a screen to prevent foreign particles from entering the nitrogen system. When the bladders **438** are removed, the male part of the quick disconnect fitting closes, preventing loss of nitrogen from the system. This vent fitting must always be removed before aerial flight of the missile **100.**

For flight of the missile **100** at maximum Mach number, the air pressure of the diffuser inlet of the turbine fuel pump **440** is sufficient to prevent cavitation during missile operation below 19,000 feet altitude. For minimum flight Mach number, the diffuser air pressure is sufficient below 8,000 feet altitude. Since the nitrogen supply is rapidly used up in low altitude flight, the check valve **450** is placed in the nitrogen pressurizing system and is connected to the air turbine inlet air. When this pressure is greater than ram pressure plus **28** psi or whenever the nitrogen supply is insufficient to provide ram pressure plus **28** psi (as would occur in a long flight of the missile **100** at high altitude which terminated in a low altitude homing phase), the check valve **450** will open, permitting this pressure to inflate the fuel pressurization bladders **438**.

This check valve **450** is of a hinge check type, and is installed transversely to the longitudinal axis of the missile **100** with the hinge forward to prevent the high boost acceleration of the missile **100** from opening the valve **450** with a corresponding loss of nitrogen.

The fuel pressurization system **228** also includes the safety nitrogen relief valve **452** for the protection of the fuel tank structure in case of failure of the nitrogen flow control unit **444**, or temporary failure thereof produces excessive inflation pressures in the bladders **438**. This valve **452** is located in line **694** between the flow control unit **444** and the inlet line **530** to bladders **438**. As shown in FIG. **69**, this safety relief poppet valve **452** is of the balanced piston poppet type and consists of a balanced piston **696** held against a circular seat **698** by a compression spring **700** and the scoop inlet pressure, in housing **702**. The spring side of the piston **696** is referenced to the inlet pressure of the air-turbine fuel pump **440** by tubing **528** and the opposite side is open to nitrogen pressure through tubing **694** for the bladders **438**. The differential pressure across the piston **696** is very nearly the differential pressure across the inner wall **454** of the fuel tank **138**. A venting outlet **704** from the valve **452** is large enough to blow off the complete nitrogen supply in case of complete failure in the flow control unit **444**.

In the event there is complete failure of the nitrogen flow control unit, that is, with all valves **446**, **448**, **650**, and **652** wide open, the safety relief valve **452** would start to open when the differential pressure across it rose to 65 psi. The maximum area of the valve **452**, is sufficient to limit the fuel tank wall differential pressure to 75 psi. The valve **452** discharges to the compartment **224** containing the nitrogen pressurization system **228**, with complete blow-off of nitrogen being insufficient to damage the compartment **224** or the fairings around the fuel tank **138**.

As shown in FIGS. **9**A, **9**B, and **13**, the function of the fuel shut-off valve **428** is to seal the fuel system at the end of the outlet line **436** of the fuel tank **138** so that the tank may remain fully fueled for an indefinite period without leakage therefrom, and to permit normal operation of the fuel system after the missile **100** is launched. It is estimated that the valve **428** will be fully open 0.1 second after firing of the missile **100**. It opens in a positive manner and is locked in the opened position during flight of the missile **100**.

The fuel shut-off valve **428** is located in the fuel system between the outlet of the fuel tank **138** and the inlet **532** of the fuel pump **440**. It is mounted to an inlet flange **706** of the fuel pump **440**, by suitable means, such as bolts or the like. The fuel shut-off valve **428** comprises a body **708**, a ball retaining sleeve **710**, a G weight **712**, a valve disc assembly **714**, a valve opening spring guide **716**, two springs **718** and **720**, eight balls **722**, a cover **724**, and O rings **726** and **728**.

The ball retaining sleeve **710** is drilled near one end **730** with eight holes **732** to contain the eight balls **722**. At the point where these holes **732** are drilled, the thickness of the sleeve **710** is slightly more than half the diameter of the balls **722**. The ball retaining sleeve **710** is held in the main body casting **708** by the valve cover **724** and is sealed against leakage by the O ring **728**. A valve stem sleeve **734** fits inside the ball retaining sleeve **710** and has two grooves **736** and **738** machined in it. The depth of these grooves **736** and **738** is slightly less than one-half the ball diameter.

A valve opening spring guide **740** fits inside the valve stem sleeve **734** and is centered by a hub **742** machined on the bottom of the ball retaining sleeve **710**. The valve opening spring **718** fits around this guide **740** and acts to force the valve disc **714** open. A valve stem **744** screws into the valve stem sleeve **734**, and passes through a centering hole **746** in the ball retaining sleeve **710**.

The G weight **712** fits around the outside of the ball retaining sleeve **710**. Its inside diameter is so machined as to hold the balls **722** in the groove **736** machined in the valve stem sleeve **734**. The G weight **712** is held in its normal position by a precision spring **720**. This spring **720** forces the G weight **712** away from the main body casting **708**.

The valve disc **714** is secured to the valve stem **744** by means of a threaded flanged collar **748**, and a pin **750**. The threaded collar **748** is held in place in the valve disc **714** by means of a shock absorbing soft rubber washer **752**, a washer **754**, and a snap ring **756**. The sealing side **758** of the valve disc **714** is fitted with an annular resilient ring **760** so designed to seal tighter in its machined seat **762** in the body casting **708** with an increase inlet pressure of the fuel from tank **138**.

Leakage around the valve stem **744**, when the valve **428** is in the open position, is prevented by the O ring **726** on the downstream side of the valve disc **714** seating in a machined seat **764** in the ball retaining sleeve **710**. Rotation between the valve stem sleeve **734**, the ball retaining sleeve **710**, and the G weight **712** is prevented by guide pins **765** and **767** riding in machined slots **769** and **773**, respectively.

In the closed position of the valve **428**, the locking balls **722** are held in the ball retaining sleeve holes **732** in a "closed position" locking groove **736** in the valve stem sleeve **734** by the G weight **712**. Screwing the valve stem **744** into the valve stem sleeve **734** seals the valve disc **714** against its seat **762**. Movement of the valve stem sleeve **734** relative to the ball retaining sleeve **710** is prevented by the balls **722**. The valve stem **744** should be tightened finger tight to prevent leakage of the fuel and to insure proper loading on the balls **722**.

When the missile **100** is launched, launching accelerations cause the G weight **712** to move against the pressure of the spring **720** toward the valve body **708**. When the G weight **712** moves toward the valve body **708**, a larger diameter on the inside of the G weight **712** is presented to balls **722**. The valve opening spring **718** acting on the valve stem sleeve **734** causes the balls **722** to move radially outward into this increased diameter, and to move out of the groove **736** machined in the valve stem sleeve **734**, unlocking said sleeve. The valve opening spring **718** causes the valve disc **714** to open and seat the O ring **726** against the ball retaining sleeve **710** and seals the stem **744** against leakage.

When the accelerations of the missile **100** decrease to near zero, the G weight spring **720** returns the G weight **712** to its normal position, forcing the balls **722** back into the second groove **738** machined in the valve stem sleeve **734**, locking the valve disc **714** in the open position. The G weight **712** functions to unlock the valve **428** when launching accelerations of the missile **100** reach between 5 and 12 g's. The valve opening spring **718** is preselected to open the valve **428**, with no fuel pressure applied to the valve inlet **434** against longitudinal accelerations up to **42.5**g and to keep the valve **428** fully open against a 29g force. Once the valve **428** is locked open, no acceleration forces applied to the missile **100** can cause it to close.

The fundamental difference from the nitrogen shut-off valve **446** and the fuel shut-off valve **428** exists in that packaging requirements for the nitrogen G valve **446** have forced the opening spring **620** of the valve **446** to work against the inertia forces acting on the valve disc **606** and stem **610.** In addition, no fuel pressure is counted upon to aid in opening the valve **446.**

The triggering weight **712** for valve **428** weighs approximately 1.6 pounds, with the design opening point being from **5** to **12** g's. As indicated, the valve opening spring **718** is capable of opening the valve **428** against 42.5g and will hold the valve **428** fully open against 29g until the acceleration of the missile **100** had decreased sufficiently for the G weight **712** to return to its original position and key the valve open. The O ring **726** fitted into the groove **766** on the back side of the valve disc **714** provides positive sealing against leakage when the valve is in the open position.

After separation of the missile **100** from the booster **500,** no maneuvering of the missile can cause the valve **428** to close. However, during ground testing of the missile **100,** the valve **428** may be activated manually and reset quickly innumerable times.

This fuel shut-off valve **428** also incorporates a torque limiting thumb screw **768** for adjustment of the valve disc **714.** This screw **768** will provide **12** to **14** pounds end thrust of the valve disc **714** against its seat **762.**

As best seen in FIGS. **9**A and **12,** the centrifugal fuel pump **440,** which is driven by a turbine **770,** is the primary source of fuel pressure required for regulation and injection of the fuel in the combustor **108.** This pump **440** provides operating heads for the various fuel components. The air turbine **770** is driven by air received by the scoop **772** in the turbine air intake strut **774** in the diffuser **270.**

The fuel pump assembly **440** consists of a cast aluminum housing **778,** the air turbine **770** with forty blades **784,** an air turbine nozzle plate **786** containing eighteen nozzles **456,** a centrifugal fuel pump **776** with four vanes **788,** and a bearing and seal assembly **790.** The air turbine **770** and the centrifugal pump **776** are mounted at opposite ends of a common shaft **780** and are sealed from each other by a high speed carbon faced mechanical seal **782.**

The air turbine **770** consists of a single stage impulse wheel **771** driven by air taken from the center of the diffuser **270** by the air intake scoop **772** in the air intake strut **774.** The air enters the wheel **771** from the eighteen converging-diverging supersonic nozzles **456,** which have a designed exit Mach number of **1.58** and a throat diameter of 0.250 inch. These nozzles **456** are mounted in the air turbine nozzle plate **786,** which is bolted to the pump body **778.** The entire pump unit **778** is mounted in the missile **100** with the nozzle plate **786** fitting into the air intake scoop **772** in the strut **774.** The air is discharged from the turbine wheel **771** into a pump compartment **792,** and led overboard by means of large louvers (not shown) installed in the missile skin **286.**

The turbine **770** is mounted, as previously mentioned, on a tapered shaft **780** and is held in place by a special torque washer **794** fitted to flats (not shown) on the shaft **780** and identations (not shown) on the turbine wheel **771.** The torque washer **794** is held in place by means of two right-hand thread lock nuts **796.**

The impeller **798** for the pump **440** is of the four vaned, single stage, single entry shrouded type and is mounted on the end of the pump shaft **780** opposite the air turbine **770,** as previously indicated. The impeller **798** discharges into an involute shaped cavity case **800** in the main body housing **778.** It is keyed to the pump shaft **780,** and held on the shaft by means of a streamlined lock nut **802.** The impeller **798** is pressure balanced to reduce axial thrust loads on the bearings **804** and **806** to nearly zero. The bearing and seal assembly **790** is mounted in the body casting **778** between the turbine wheel **770** and the pump impeller **798.**

The two ball bearings **804** and **806** are mounted on the shaft **780,** with one being located at each end of the bearing and seal assembly **790.** Each of these bearings **804** or **806** is designed to take radial thrust in all directions and axial thrust in one direction. These bearings **804** and **806** are mounted back to back so that axial thrust in either direction is taken up. The bearings **804** and **806** are held in place by steel snap rings **808** and **810,** respectively.

The carbon seal assembly **782** is mounted between the bearings **804** and **806.** The seal **782** consists of a flanged sleeve **812** rotating with the shaft **780** and an annular spring loaded carbon seal **814** which is mounted in the bearing and seal assembly **790.** It rides against the flange **816** on the rotating sleeve **812.** This seal **814** prevents leakage of the fuel past a pressure balancing seal **818** and through the impeller bearing **804** down the shaft **780** to the turbine bearing **806** and the turbine exhaust air stream. Leakage past the impeller bearing **804** is vented through line **820** back to the inlet side **532** of the pump **440.**

The impeller bearing **804** is cooled and lubricated by the fuel leaking past it to the carbon seal **814.** The turbine bearing **806** is packed in a high temperature grease for lubrication. The entire bearing and seal assembly **790,** as indicated, is mounted in the body casting **778** and is sealed against fuel leakage between the assembly housing **822** and the body casting **778** by O rings **824** and **826.** The bearing and seal assembly **790** is held in place by a large spanner nut **828** which fits over the bearing and seal housing **822** and is screwed and lock-wired to the central portion **830** of the body casting **778.**

The discharge pressure of the pump **440** is between **300** psi and **400** psi at sea level depending on flight velocity of the missile **100.** The speed of the pump **440** is between 20,000 and 30,000 rpm at sea level under expected operating conditions. The maximum design rotational speed of the pump **440** is 40,000 rpm. The turbine wheel is spin tested under load to 50,000 rpm during check out of the pump **440.**

The fuel strainer **458** is also provided in the fuel control system **230** to prevent contaminating particles from entering both the pilot and main fuel systems.

As shown in FIG. **10,** this fuel strainer **458** includes a housing **832** which is integral with the main fuel regulator **380.** One end **834** of the housing **832** is externally threaded to receive a threaded ring **836** for securing a flange **838** of an accordian type flexible connector **840** thereto. This connector **840** connects the outlet **842** from the fuel pump **440** to the fuel strainer **458.** The other end **844** of the housing **832** is internally threaded to receive an end cap **846.** This end cap **846** is utilized to close end **844** of the housing, after a strainer element **848,** which consists of a hollow sintered bronze cylinder, having a length of 6.875 inches, with outside and inside diameter of 2.438 inches and 2.094 inches, respectively, is inserted in the housing **844.** A coiled spring **850,** located between a centering element **852** and the end cap **846,** is utilized for centering the strainer element **848** in the housing **832.**

The fuel from the fuel pump **440** enters the fuel strainer **458** through end **834** of the housing and is passed through the strainer element **848.** The fuel then filters outward through the strainer element **848** to an annulus **854** surrounding the element **848.** This annulus **854** feeds into the entrance passages **856** and **858** of the main and pilot fuel regulators **380** and **340,** respectively. The strainer element **848** is capable of trapping all particles with a dimension greater than 0.001 inch. O rings **860, 862,** and **864,** are utilized to seal the fuel strainer **458** from leakage of fuel therefrom.

The pilot fuel regulator **340** is designed to provide the required fuel flows to the pilot section **320** of the combustor **108** to insure a stable pilot frame which is not affected by the velocity of the missile **100.** The pilot section **320** of the combustor **108** uses about **20** percent of the air flow passing through the combustor, and it operates at a nearly constant equivalence ratio of 1.4 which insures stable operation of the combustion system at all times. The fuel flow for the main combustor is influenced by a velocity control mechanism. It may exceed the limits required for stable operation, with the result that the ramjet flame may be extinguished without the stabilizing influence of the pilot section **320.** This is especially true at high altitudes.

The air-fuel ratios are rich to insure stable operation of the combustion system. However, it has been determined that a leaner mixture is most suitable for ignition. During the starting period, use of a lean mixture helps to eliminate or reduce violent explosions. In order to obtain a leaner mixture in the pilot section **320,** a squib activated unit **866** allows the pilot regulator **340** to deliver an air-fuel ratio of 0.0663 until ignition of the fuel takes place shortly after separation of the missile **100** from the booster rocket **500.** One to 3 seconds after ignition of the fuel, the squib unit **866** operates, raising the air-fuel ratio to the normal rich value.

In order to obtain the required air-fuel ratios, the pilot regulator **340** must deliver fuel flows which vary from 4.5 lb/sec to less than 0.3 lb/sec depending on altitude and speed. Air-fuel ratios must be held to within ±10 percent of the required values from sea level to 30,000 feet, and within ±5 percent from 30,000 to 60,000 feet.

The pilot regulator **340,** which delivers the required fuel flow, derives its intelligence from two pressure pick-up points on the missile **100.** Referring now to FIGS. **7, 9A, 9B,** and **11,** of the drawings, the ram pressure pick-up probe **128** is located at the forward end of the inner body **120,** with the ram pressure being piped by aluminum tubes **868, 870,** and **872,** to the pilot and main regulators **340** and **380,** and the nitrogen flow control unit **444.** Atmospheric pressure is picked up by four body static taps **130,** located on the missile skin on the forward body assembly **102.** The pressures picked up from these four ports **130,** are manifolded together and piped through aluminum tubes to the main and pilot regulators **340** and **380.** Air flow through the ramjet engine is approximately proportional to ram pressure over the designed Mach number range. The fuel flow delivered in proportion to ram pressure will, therefore, maintain a desired and nearly constant air-fuel ratio.

This pilot regulator **340** is comprised of an altitude controlled variable area orifice and a pneumatically referenced pressure regulating linkage which controls the fuel pressure drop across the variable area orifice. Since the fuel is considered incompressible, the pilot regulator **340** thereby becomes independent of the outlet and inlet pressures provided the inlet pressure is sufficiently greater than the outlet pressure for the throttling type pressure regulating linkage to operate.

The variable area orifice consists of a contoured valve **874** whose travel is controlled by a servo type positioning mechanism **876.** The fuel inlet pressure of the pilot regulator **340** is utilized as the high pressure source for the servo positioning mechanism **876,** while atmospheric pressure is used as the low pressure source for the servo positioning mechanism.

A pilot valve **878** of this mechanism **876** is connected to an evacuated altitude bellows assembly **880** which senses altitude static pressure. Motion of the valve **878** is then a function of altitude. There is a negligible error due to the influence of fuel inlet pressure on the servo positioning mechanism **876.** The required contouring of the valve **874** is determined by finding the required area from the characteristics of the pressure regulating linkage and the required fuel flow variation with altitude, and coordinating this area with the altitude-travel relationship of the evacuated bellows assembly **880,** as indicated in Equation (3) below:

$$A = \frac{F.\,F.}{\sqrt{2\,g\,d\,\Delta p}} \qquad \text{Eq. (3)}$$

where

A = area in square feet;
$F.F.$ = required fuel flow pounds per second;
C = coefficient of discharge of the valve;
g = acceleration due to gravity in feet per second per second;
d = fuel density in pounds per cubic feet; and
Δp = controlled differential pressure across the valve in pounds per square feet.

The pressure regulating linkage is comprised of a poppet valve **882** which is controlled by two opposed equal area fuel and air pistons **884** and **886,** respectively. A reference differential pressure is imposed across the air piston **886** by the pneumatic control circuit, and the resulting force is opposed by a force generated on the fuel piston **884** by the differential pressure across the variable area contoured valve **874.** Any unbalance causes motion of the poppet valve **882,** with a corresponding change in the amount of throttling of the fuel flow.

The change in fuel flow alters the differential pressure across the variable area contoured valve **874,** and thereby alters the force of the fuel piston **884.** The poppet valve **882** will move until equilibrium of forces is established. Such motion will occur whenever the differential pressure of the air piston **886** changes or whenever the inlet or outlet pressures of the pilot regulator **340** change. The differential pressure of the variable area altitude valve **874** is thus controlled and is equal to the differential pressure of the air piston **886.**

At any constant altitude of the missile **100,** the fuel flow is arranged to vary with ram pressure. Since the area of the metering orifice **888** in the variable area altitude valve **874** is fixed (constant altitude), the variation must be provided for by the differential pressure of the air piston **886.** The constant of proportionality may be a function of altitude as this can be accounted for in the contour of the variable area altitude valve **874.**

Since, at constant altitude, the fuel flow is proportional to the square root of the pressure differential across the variable area altitude valve **874** and the pressure differential of the air piston **886** equals the pressure differential of the variable area altitude valve **874,** the pneumatic control circuit is required to produce a differential air pressure whose square root varies with ram pressure.

This is accomplished by a pair of restrictions **890** and **892** in series in a pneumatic control circuit **894** which pass air from ram pressure to body static pressure. The square root of the pressure drop across the downstream restriction **892** will very closely approximate the desired proportion over the range of applicable Mach numbers of operation of the missile **100.**

Since ramjet ignition must occur quickly at separation, the time delay unit **866** is provided as a modification to the pneumatic control circuit **894.** During the boost phase of the missile **100,** and the separation thereof from the booster **500,** an additional passage **896** is opened in parallel with the downstream restriction **892** of the control circuit **894** in order to lower the air piston differential pressure below its normal value. This conserves fuel during the boost phase after the fuel shut-off valve **428** has opened and provides a leaner mixture to the pilot section **320** of the combustor **108** for more favorable starting of the ramjet engine. At separation of the missile **100** from the booster **500,** two instantaneous squibs in the time delay unit **866** explode to close a valve which shuts off this parallel restriction **896,** with the result that the differential pressure of the regulator air piston **886** then quickly returns to its normal condition in approximately 0.8 seconds.

For purposes of clarity, the pilot regulator **340,** FIG. **11,** has been illustrated semi-schematically and various minor details have been deleted. The pilot regulator **340** has a body casting **898.** Various channels are provided in the casting walls for transferring the fuel and air pressures used in the regulator **340.** In actual practice, bosses are provided on the castings to permit pressure pick-offs to be used for testing and calibrating the regulator. All moving parts within the regulator subject to wear or corrosion are made of stainless steel. Two types of gaskets are used in the pilot regulator **340** to prevent air and fuel leakage, namely, flat type gaskets and O ring type gaskets. O rings are used in various sizes through the pilot regulator **340.**

In practice, a poppet valve sleeve (not shown) is fitted into the fuel inlet side of the pilot regulator body casting **898.** It is made of a stainless steel piece and it is sealed at each end by O rings. Four ports cut around the sleeve permit fuel flow through the sleeve. The top edge **900** of the poppet valve **882,** which is wedged shaped to reduce Bernoulli effects, meters the fuel flowing through the sleeve ports. The bottom end of the valve is blanked off except for two apertures **902** and **904.** One aperture **902** is used for attaching the valve **882** to the valve rod **906;** while the second aperture **904** is used to equalize the pressures above and below the blanked end of the valve. Slots are cut in the bottom of the valve to reduce weight thereof and G forces in flight. These slots are cut in the valve **882** below the level of lower edges of the fuel ports cut in the valve sleeve when the poppet valve **882** is closed. A sleeve cover holds the sleeve in place in the pilot regulator body by means of lock wired screws, and it is sealed against fuel leakage by an O ring.

A baffle, at **908,** is provided in the regulator body directly above the poppet valve sleeve. The baffle **908** reduces turbulence and local high velocity jets of fuel from the metering edge **900** of the poppet valve **882** and delivers an even pressure to the bottom of the fuel piston **884.**

The clearance between the disc and the regulator casting **898** provides means for applying partially metered fuel pressure (altitude valve inlet pressure) to the bottom of the fuel piston **884.** The center of the baffle disc is drilled for the fuel piston rod. Fuel flows from the poppet valve **882** into the open end of the baffle **908,** then radially through the perforated walls to a fuel collecting annulus. Clearance between the baffle disc and the pilot regulator body casting **898** allows fuel as near static pressure as is possible, to be applied to the bottom **910** of the fuel piston **884.**

A spacer fits into the regulator body above the baffle. The fuel piston sleeve contains a shoulder at the top. An O ring prevents fuel leakage between the sleeve, spacer, and regulator body **898.** The fuel piston end of the rod **906** is drilled and tapped and the piston is bolted to the rod. The other end of the rod **906** is threaded for the poppet valve **882.** The poppet valve **882** is attached by first placing a spring bushing **912** on the rod **906,** over which is placed a poppet valve spring **914.** The poppet valve **882,** metering edge **900** toward the fuel piston **884,** is then placed on the shaft bearing against the spring **914.** Double washers **916** of the ball and socket type are then placed on the rod **906** and bear against the poppet valve **882.** The assembly is held together with a lock nut **918.** The ball and socket washers **916** and the spring **914** prevent any misalignment of the rod **906** from binding the valve **882.**

The air piston housing, shown here as being cast integral with the regulator casting **898,** is in actual practice a cast aluminum housing. The top end of the housing is open. The lower end **920** of the housing is closed except for a hole **922** in the center. A force pin **924** fits in a bushing (not shown) pressed in this hole **922** with a minimum clearance to permit frictionless movement but to prevent excessive fuel leakage. The low side of the air piston **886** communicates with the body static ports **130** by means of passage **926** and tubing **928.**

A air piston sleeve (not shown) fits into the air piston body, with an "O" ring seal being utilized to prevent air leakage between the body and a shoulder of the sleeve.

The air piston **886** is, hand lapped to the sleeve. The air piston **886** bears against the force pin **924** which transfers the motion of the air piston **886** to the fuel piston **884** and poppet valve **882.**

The air piston has a cover (not shown). Four bolts secure the cover and air piston housing to the regulator body **898.** Flat gaskets provided between the regulator body **898**, the air piston housing, and air piston housing cover seal the regulator **340** against fuel and air leakage.

The regulator **340** is provided with two passages **930** and **932** through which air flows from the ram pressure pick-up **128** to the atmospheric pressure outlets **130**. These passages **930** and **932** are provided at one end with the bleeds **890** and **892** respectively. The inlet passage **930**, connected to the ram pressure pick-up **128**, contain bleed **890**. The outlet passage **932**, connected to the body static pressure ports **130**, contains bleed **892**. The pressure generated in the passage between these bleeds **890** and **892** is applied to the top (high pressure) side of the air piston **886**. The downstream bleed **892** is tailored to give proper air heads. In addition to the inlet and outlet passages **930** and **932**, the air piston communicates with the time delay unit **866** by means of passage **896** and tubing **934**.

It is to be noted that the air piston **886**, fuel piston force pin **924** and fuel poppet valve **882** are termed the fuel metering linkage. The fuel downstream of this linkage is termed partially metered fuel.

A sleeve **936** is provided in the variable area contoured valve **874**. This sleeve **936** is mounted into the regulator body casting **898** on the downstream side of the fuel metering linkage. Four ports **938** are cut through the sleeve **936** to permit passage of fuel through the sleeve. Each end of the sleeve **936** is sealed against fuel leakage between the sleeve and the body casting by **0** rings (not shown).

The variable area altitude valve **874** (variable area orifice valve) is a piston type valve. The bottom **940** of the valve **874** is open. The top **942** of the valve **874** is completely closed, and is tapped (shown integrally in FIG. **11**) to receive a servo follower rod **944**. Six ports (only one **888** of which is shown) are cut in the valve **874** to permit fuel flow through the valve.

The ports, such as port **888**, are designed to give proper fuel flows at each altitude with air piston differential pressure across the valve **874**. The ports are 0.620 inch long, with the top of the ports 0.825 inch from the top **942** of the valve **874**. When the valve **874** is fully open, the maximum port area is aligned with the sleeve ports **938**, and maximum fuel flow results. As the valve **874** is closed, it is moved toward the regulator outlet **946**, and the port area is decreased. The position of the valve **874** is a function of altitude. This will be discussed more in detail subsequently. To prevent the valve **874** from turning in its sleeve **936**, a pin (not shown), secured to the sleeve **936**, rides in a slot (not shown) machined parallel to the axis of the valve **874**.

The variable area altitude valve **874** is provided with a coil spring **948** carried by a spider **950**. This spring **948** applies a force to the altitude valve **874** that tends to open the valve. This force is overcome by the action of the altitude valve servo mechanism **876** described below.

A fuel outlet elbow **952**, FIG. **8**, is bolted to the pilot regulator body **898** below the altitude valve assembly **874**. A flat gasket is utilized to seal the body casting **898** and the outlet elbow **952** against fuel leakage.

A regulator outlet pressure pick-up **954** is mounted in the regulator outlet **946**. An end **956** of the pressure pick-up **954**, which projects into the fuel stream, is closed. Two apertures **958** drilled in the side of the tube are used to pick up the pressure. The other end **960** of the pressure pickup **954**, which is secured to the regulator outlet **946**, is sealed with an **0** ring (not shown). It is connected to the low pressure side of the fuel piston **910** by passage **962** provided in the body casting **898**.

The altitude bellows **880** is of the sealed, evacuated, spring loaded type. The free length of the bellows **880** at sea level is approximately 1 ½ inches. One end **964** of the bellows **880** is fixed, while the other end **966** is free to move. The bellows **88**, as mounted, has atmospheric pressure applied to the space surrounding it so that with a decrease in atmospheric pressure, it will increase in length.

The free end **966** of the bellows **880** is connected by a thin rod **968** to an altitude valve servo piston **970**, and moves about 0.018 inch per inch mercury change of barometric pressure. The bellows **880** will increase approximately one-half inch in length with a pressure change surrounding it corresponding to an altitude change from sea level to 60,000 feet. The fixed end **964** of the bellows **880** is closed by means of a cap **972** that is threaded for adjustment purposes. The cap **972** is locked with a nut **974** after adjustment.

The servo mechanism pilot valve **876** is designed to position the variable area altitude valve **874** with respect to the free end of the altitude bellows **880** and to make the motion of the contoured altitude valve **874** (variable area valve) correspond exactly to the motion of the altitude bellows. The high pressure of the fuel at the inlet **976** of the pilot regulator **340** is the actuating medium for this pilot valve. Under equilibrium conditions, high pressure fuel fills an annulus **978** between the servo piston **970** and the servo follower **980** by flow through a servo follower inlet annulus **982**. The servo piston **970** is pressure balanced by means of a hole **984** through the pilot valve to eliminate forces on the piston ends.

As altitude of the missile **100** is increased, the altitude bellows **880** expands. Since the rod **968** is linked to the servo piston **970**, it moves the servo pilot valve **878** toward the altitude valve **874**. For any given altitude, the position of the altitude bellows **880** and servo piston **970** is fixed. this motion of the servo piston **970** uncovers ports **986** in the servo follower **980**, venting high pressure fuel through the ports **986** to the top **942** of the altitude valve **874**. Venting of the high pressure fuel to the top **942** of the altitude valve **874** causes this valve to move downward (toward the closed position).

As the valve **874** moves, it carries the servo follower **980** with it due to the rod **944** between them. As the servo follower **980** moves, the high pressure ports **986**, carrying fuel to the top **942** of the altitude valve **874**, move under the lands **988** of the servo piston **970**, and the flow of fuel is shut off, stopping the motion of the altitude valve **874**. As the missile **100** decreases in altitude, the altitude bellows **880** contracts, and through the rod linkage **968**, mves the servo piston **970** away from the altitude valve **874**. This motion of the servo piston **970** uncovers the ports **986** in the servo follower **980** and vents pressure from these ports to an overboard drain **990** by means of a tube **992**. As the pressure is released from the top **942** of the altitude valve **874**, the force of the altitude valve spring **948** and the regulator outlet pressure move the altitude valve **874** toward the open position, causing the servo follower **980** to move so as to cover the ports **986** in the servo follower with the pilot valve lands **988**.

In actual practice, the servo mechanism **876** is carried by a servo sleeve (not shown) pressed into the servo housing, which is, in turn, bolted to the main body casting **898.** Passages **944** and **946** in the regulator **340** permit flow of fuel pressures to and from the servo mechanism **876.** The servo follower **980** is a hollow spool type valve. The servo piston **970** is a spool with two lands **988,** one at each end, which are hand lapped to the inside diameter of the servo follower **980.**

as illustrated in FIg. **70,** the squib activated time delay unit **866** comprises a body **988** containing a spring loaded valve **1002** held in the open position by a fine wire **1004.** The inlet **1006** to the unit **866** contains a bleed (not shown) vented to atmosphere which parallels the outlet bleed **892** in the air piston circuit when the spring loaded valve **1002** is in the open position. The use of the aforementioned bleed to parallel the outlet bleed **892** causes a reduction in air piston differential pressures, and reduces the fuel flow to the valve necessary to give a 0.0663 air-fuel ratio for starting. Shortly after the missile booster separation, a time delay relay ignites an instantaneous squib **1006** which severs the fine wire **1004** holding the time delay unit **866** open, permitting the valve **1002** to close and take the bleed at inlet **1006** out of the circuit. This returns the pilot regulator **340** to normal operation.

The operation of the pilot regulator **340** will not be explained, starting with an explanation of the missile **100** on the launcher **1000.** While the missile **100** is on the launcher **1000,** no air pressures or fuel pressures are imposed on the pilot regulator **340,** and consequently no fuel flows. During boost of the missile **100** by the booster **500,** ram pressure is built up, creating air heads on the air piston **886.** These air heads are lower than normal due to the bleed in the squib activated time delay unit **866** being parallel with the air piston air circuit. During boost, therefore, fuel flow has started, and fuel has filled the lines to the pilot regulator **340,** the main regulator **380,** and the lines to the fuel injector systems **320** and **378.** By the time of separation of the missile **100** and the booster **500,** fuel has started to flow from the pilot injectors **330,** and the pilot igniter **1008** is ignited.

After separaton of the missile **100** from the booster **500** and ignition of the pilot igniter **1008,** the squib activated time delay unit **866** is fired, and the bleed is taken out of the air circuit so that air heads and fuel flow go to normal design values. the altitude valve **874** has been moved to the proper position by the action of the altitude bellows **880** and the altitude servo mechanism **876.** The fuel flows, as necessary, to give an air-fuel ratio of 0.0934 (up to 40,000 feet).

Let it be assumed that at an altitude of 5,000 feet, the missile **100** flies a level course, and it has a velocity of 1,900 ft/sec. The pilot air-fuel ratio will be at 0.0934. The main regulator **380** will be delivering enough fuel to accelerate the missile **100.** As the missile **100** accelerates to 2,000 ft/sec, the ram air pressure increases to increase the pressure on the high side of the air piston **886.** The pressure on the low side will be constant at body static pressure. The higher differential pressure across the air piston **886** moves the fuel metering linkage in such a manner as to impose the same differential pressure across the variable area altitude valve **874.** As fuel flow through this valve **874** is proportional to the square root of the differential pressure (air piston differential pressure) across it, fuel flow through the pilot regulator **340** increases, as necessary to maintain a constant air-fuel ratio.

Let it now be assumed that the missile **100** is flying at 45,000 feet, with a speed 2,000 ft/sec. As the missile **100** climbs, ram pressure, static pressure, and fuel inlet pressure will decrease, the air iston **886** differential pressure will also decrease. At the same time, the pressure at the fuel inlet **976** will decrease, and the fuel metering linkage will move in such a manner as to impose air piston differential pressure across the variable area altitude valve **874.** As the static pressure decreases, the altitude bellows **880** and servo mechanism **876** will cause the altitude valve **874** to move toward the closed position, reducing the port area available for fuel flow. The altitude valve ports **888** have been so designed to give a fuel flow corresponding to an air-fuel ratio of 0.0868. Since fuel and air flow through the missile **100** are both proportional to the square root of air piston differential pressure, this air-fuel ratio will be maintained at all velocities at this altitude.

In order to insure that adequate airheads are provided on the pilot regulator **340** of sufficient magnitude to overcome the acceleration forces during boost of the missile **100** and to insure fuel flow from the pilot injector at separation of the missile from the booster **500,** regulated nitrogen pressure (pressure plus 28 psi) can be bled into the pilot regulator ram line. If this is done, a check valve should be added in the ram line to the pilot regulator **340** to prevent loss of nitrogen through this line, and a bleed should be installed in the regulated nitrogen line to the pilot regulator ram connection to adjust the nitrogen pressure applied to the high pressure side of the air piston. This bleed should be chosen so as to give the normal operating air heads on the air piston (normal rich pilot fuel flow) at separation. The pressures applied by the regulated nitrogen and the rate of pressure rise is such that, at separation of the missile **100** from the booster **500,** the tube volume between the pilot regulator **340** and the pilot injector is filled, and fuel flows from the pilot injector.

At separation of the missile **100** from the booster **500,** a squib activated valve can be utilized to shut off the regulated nitrogen to the pilot regulator **340.** At this time, ram air opens the ram line check valve mentioned above, and the pilot regulator **340** now operates normally. It will be noted that at this time, the lean start time delay unit is in the circuit, and the pilot regulator **340** immediately goes to lean start operation. At approximately 2.2 seconds after separation of the missile from the booster, the lean squib unit operates, and returns the pilot regulator **340** to normal, rich stable burning operation.

The main fuel regulator **380,** as shown in FIGS. **9A, 9B** and **10,** controls the delivery of the fuel to the main section **376** of the combustor **108** of the ramjet engine at various flight conditions of velocity and altitude, and operates in such a manner as to satisfy the engine requirements using MIL-F-5616 kerosene or the equivalent. This regulator **380** controls fuel flows within the desired limits from sea level to 60,000 feet altitude so as to produce a missile flight air speed of 2,000 ft/sec ± 5 percent by raising or lowering the fuel flow to the main section **376** of the combustor **108,** thus increasing or decreasing thrust as required.

The fuel flow must vary with ram pressure at a constant altitude from a Mach number equal to 1.725 to the lower velocity control limit. The regulator **380** is programmed with altitude to provide an equivalence ratio of approximately 0.8 to the main section **376** of the combustor **108.** The acceleration of the missile **100** will be reduced until zero acceleration or constant velocity flight of the missile results. Extreme climb, dive, or maneuver, where the full range of fuel flows may not be sufficient to produce a zero acceleration condition of the missile **100,** may cause the missile **100** to depart from the controlled velocity region until such flight conditions have been attenuated. Such conditions, however, will be of very short duration.

Velocity control of the missile **100** is accomplished, as previously mentioned, by sensing the stagnation temperature, ram pressure, and static pressure. Equation (4) below illustrates how these quantities determine the velocity of the missile **100**:

$$\frac{P_r}{P_a} = \left[\frac{1.2\ V^2}{2401\ T_s - .2V^2}\right]^{3.5} \left[\frac{6(2401\ T_s - .2V^2}{7.2\ V^2 - 2401\ T_s}\right]^{2.5} \qquad \text{Eq. (4)}$$

where

P_r/P_a = ratio of ram to static or ambient pressure;

V = velocity in feet per second;

T_s = stagnation temperature in degrees Rankin; and

K = ratio of specific heats at constant pressure and volume (assumed as 1.4 for air).

Air at ram pressure is fed to a circuit consisting of a fixed inlet bleed **1010** and a variable area outlet bleed **1012** and it is discharged at static pressure. The variable area bleed **1012** is powered by a bellows **1014** so that its motion is proportional to the differential pressure across the bellows. This differential pressure is the output of a temperature pick-up unit **1016** consisting of a thick, high response bimetallic element **1018** projecting into the diffuser **270** of the missile **100** which controls the pressure drop across a light poppet valve **1020** in series with a small bleed **1022.** The output of this device **1016** is essentially proportional to stagnation temperature and independent of altitude and the pressure of the diffuser **270** as indicated by Equation (5) below:

$$P = T_s/90 \qquad \text{Eq. (5)}$$

where

P = differential pressure output in pounds per square inch; and

T_s = stagnation temperature °F.

The variable area bleed **1012** is contoured in such a manner that the pressure ratio across it, which is determined by stagnation temperature and the ratio of ram to atmospheric pressure, becomes approximately a simple linear function of velocity, as indicated by Equation (6) below:

$$P_x/P_a = 0.00605V - 8.3 \qquad \text{Eq. (6)}$$

where

P_x/P_a = pressure ratio across the downstream (contoured) bleed; and

V = velocity in feet per second.

This pressure ratio is applied to an evacuated double Mach sensing bellows assembly **1024** which has a fixed end **1026** and a free end **1028** which is connected to a balanced air piston shorting valve **1030.** The behavior of the Mach sensing bellows **1024** is such that at a pressure ratio equal to the area ratio of the two bellows **1033** and **1035,** the free end **1028** is always in the same position. A greater pressure ratio causes motion in one direction and a lesser pressure ratio causes motion in the opposite direction. The area ratio of the Mach sensing bellows **1024** is equal to the pressure ratio existing across the contoured bleed **1012** at the lower design limit velocity, with the valve **1030** being set on the verge of opening at this condition. At all lower velocities, the valve **1030** remains closed, but as the lower design velocity is exceeded the valve **1030** begins to open. The valve **1030** is fully open by the time the upper design velocity is reached.

A small piston **1032** is also connected to the free end of the Mach sensing bellows **1024.** It is fed by the high side pressure of the air piston **1034** and a separate double restriction air circuit **1036.** Its purpose is to help equalize the sensitivity of control with changes in altitude of the missile **100** by preventing excessive travel of the valve **1030,** with a given velocity overshoot at low altitude, thereby allowing high altitude sensitivity to be increased while holding a given maximum sea level sensitivity. The Mach sensing bellows **1024** is adjustable such that the presently specified 2,100 ft/sec control velocity is achieved within ± 100 ft/sec limits.

The ram (free stream pitot total) pressure probe **128** supplies one of the necessary intelligence measurements for the fuel regulators **340** and **380,** and it is located, as previously mentioned, at the stagnation point at the forward tip of the inner body **120.** The aluminum tube line **868** leads back through one of the center body support struts **324** to the fuel regulation compartment **226.**

Air flows from the control circuitry of the fuel regulators **340** and **380** are discharged to the aluminum tubing line lines **928, 1038, 1040,** and **1042** which run to the four body static vents **130** in the external surface of the missile **100** where the forward body section **102** and the center body section **106** come together. Due to the air flow in the body static lines **928, 1038, 1040** and **1042** and the external flow pattern of the missile **100,** the static pressure in these lines in the vicinity of the regulators **340** and **380** is not an accurate intelligence of static pressure.

A velocity control mechanism **1044** which requires an accurate static pressure measurement obtains this measurement from a static probe **126** extending in front of any probable flight normalshock position. There is no flow in a line **1046** which connects the probe **126** to the velocity contro l mechanism **1044,** but a pressure relief valve **1048** is provided to relieve the high pressure generated during the boost phase of aerial flight of the missile **100** when a shock wave is pushed out in front of the missile to such a location that the pick-up apertures in the static pressure probe **126** are in a region of higher than static pressure. This pressure relief valve **1048** is of a ball-check relief type, and requires a differential opening pressure of 4.5 to 7.5 psi. It is located in the fuel system compartment **226,** and is, therefore, referenced to the pressure in this compartment.

In FIG. **10,** the main fuel regulator **380** comprises a main body casting **1050** in or on which are mounted the following assemblies: the inlet fuel strainer **458,** a sensitivity equalizer **1052,** the Mach sensing bellows assembly **1024,** the air piston shorting valve **1030,** the air piston **1034,** a fuel piston **1054,** a fuel flow straightener **1056,** a fuel poppet valve **1058,** the previously mentioned velocity sensing bellows **1014**, the variable area bleed **1012**, an altitude sensing bellows **1060**, a variable area orifice servo **1062**, and a variable area orifice valve (altitude valve) **1064**.

The Mach sensing bellows **1024** is an evacuated double bellows assembly consisting of the two bellows **1033** and **1035**. One end **1026** of the Mach sensing bellows **1024** is fixed to a fitting **1068** and the other end **1028** is free. The free end **1028** of the Mach sensing bellows **1024** is connected to the air piston shorting valve **1030** by a thin force pin **1070**. The output pressure from the velocity sensing unit **1072** is applied to the inner bellows **1035** through a passage **1074** provided in fitting **1068**, and atmospheric pressure is applied to the outer bellows **1033** by means of tube **1046**.

The area ratio between the inner and outer bellows **1035** and **1033**, respectively, at the free end of the Mach sensing bellows **1024** is equal to the ratio of ram pressure to atmospheric pressure at a Mach number equal to **1.6**; that is, the area of the outer bellows **1033** is 3.8 times the area of the inner bellows **1035**. At pressure ratios lower than that corresponding to approximately a Mach number of 1.4, the free end **1028** of the Mach sensing bellows **1024** rests on mechanical stops (not shown) built into the Mach bellows mounting.

At pressure ratios above that corresponding to a Mach number equal to 1.4, the Mach sensing bellows **1024** increases its length. At a Mach number of 1.6, the length of the Mach sensing bellows **1024** is equal to that of an unevacuated bellows. Increasing pressure ratios causes the Mach sensing bellows **1024** to further increase its length. As the air piston shorting valve **1030** is mechanically linked to the free end **1028** of the Mach sensing bellows **1024**, its motion corresponds directly to that of the Mach sensing bellows.

The air piston shorting valve **1030** is comprised of a spool **1076** located in a valve sleeve **1078**. It is positioned by a spring **1080** located at one end of the valve sleeve housing **1082** and the force pin **1070** from the free end of the Mach sensing bellows **1024** at the other end. The valve spool **1076** is pressure balanced by means of a longitudinal passage **1084** through its center which vents the outlet pressure of the velocity sensing assembly **1072** from passage **1086** to both ends of the spool **1076**, thereby eliminating any pressure unbalance on the spool. The valve sleeve **1078** is mounted in the base of the air piston assembly cover **1088**.

The sleeve **1078** contains two annular ports **1090** and **1092**. Port **1090** connects directly to the high pressure side of the air piston **1034** through passage **1094** while the other port **1092** connects to the low pressure side of the air piston **1034** through passage **1096** and through a No. 56 bleed **1098** to the body static ports **130** through passage **1100** and tube **1038**. At low flight Mach numbers, an upper land **1102** of the shorting valve **1030** is covering the ports **1092** leading to the low pressure side of the air piston **1034**. The inlet ports **1090**, from the high pressure side of the air piston **1034**, are never covered by the valve spool **1076**. By venting the high side pressure of the air piston **1034** to the inside ends of both lands **1102** and **1104**, pressure balance on the spool **1076** is maintained.

As the Mach sensing bellows **1024** sees a Mach number slightly below a value of 1.6, it free end **1028** has moved enough to allow the shorting valve **1030** to be on the verge of uncovering the sleeve port **1092** to the low pressure side of the air piston **1034**. As the Mach number, as seen by the Mach sensing bellows **1024**, increases slightly, the shorting valve **1030** begins to open and reduce the pressure on the high pressure side of the air piston **1034**, venting it to the low pressure side of the air piston and to atmosphere. When the Mach sensing bellows **1024** sees a Mach number equal to 1.6, the differential pressure (high pressure minus low pressure) of the air piston **1034** has decreased by about one third. When the Mach sensing bellows **1024** sees a Mach number equal to 1.6, the velocity of the missile **100** should be 2,000 ft/sec. As the air piston shorting valve **1030** begins to open, the sensitivity equalizer **1052**, which is located on the top of the Mach bellows housing **1066**, comes into action as will be explained below. When the shorting valve **1030** opens further, the differential pressure of the air piston **1034** drops to zero.

The air piston **1034** is of the free floating type. A corrected ram pressure from the spillover bleed circuit is fed by tube **872** to the high pressure side of the air piston **1034** and atmospheric pressure by passage **1096** to the low pressure side of the air piston **1034**. The force imposed on the air piston **1034** by this differential pressure is applied to the fuel piston **1054** by means of a force pin **1106** which passes through the body casting of the air piston **1034**.

The lower side of the fuel piston disc **1054** is connected to the fuel poppet valve **1058** by a fuel piston rod **1108**. The upper side of the fuel piston **1054** has forces applied to it by means of the force pin **1106** from the air piston **1034**. Partially metered fuel pressure is fed from the fuel flow straightener **1056** to the high pressure side of the fuel piston **1054** through a tube **1110** having apertures **1112** therein. Fully metered fuel pressure is fed to the low pressure side of the fuel piston **1054** through a passage **1114** connected to a tube **1116** having a pressure pick-up point **1118** located in the outlet **1120** of the main fuel regulator **380**.

The force imposed on the fuel piston **1054** by this differential pressure is opposed to the force applied by the differential pressure of the air piston **1034**. These forces are equal when the system is in a stable metering state. A change in the force balance due to a change in the air heads, or the fuel pressures, causes the fuel metering linkage (air piston **1034** and force pin **1106**, fuel piston **1054** and piston rod **1108**, and fuel poppet valve **1058**) to move in such a manner as to restore the force balance. Thus, a drop in air piston differential pressure would cause the entire linkage to move upward toward the closed position of the fuel poppet valve **1058** until a new equilibrium point is reached.

The fuel flow poppet valve **1058** is of the stainless steel piston type. It is connected to and actuated by the fuel piston **1054**. It fits into a poppet valve stainless steel sleeve (not shown) which, in turn, fits the fuel inlet side of the regulator body casting. It is sealed at its ends by O rings. This is the first point of the fuel flow metering and it will control the differential pressure across the variable area orifice valve **1064** as determined by the differential pressure of the air piston **1034** (missile velocity). When the poppet valve **1058** moves toward the Mach sensing bellows **1024**, the fuel flow is reduced. Four ports (not shown) are cut around the sleeve to permit fuel flow through the sleeve.

The bottom end **1122** of the poppet valve **1058** is blanked off except for two holes **1124** and **1126**. The hole **1124** in the center of the valve **1058** is used for attaching the valve to the valve rod **1108**; while the second hole **1126** is utilized to equalize the pressures above and below the blanked end **1122**. Slots (not shown) can be provided in the bottom of the valve **1058** to reduce weight and G forces during the flight of the missile **100**. These slots are cut in the valve **1058** below the level of the lower edges of the fuel ports in the valve sleeve (not shown) when the poppet valve **1058** is closed.

In practice, a sleeve cover holds the sleeve in place in the regulator body by means of lock wired screws, and is sealed against leakage by an O ring. The valve rod **1108** is attached to the valve **1058** by means of a nut **1128** which engages the threaded end of the rod **1108**. A coil spring **1130**, together with a flange ring **1132** mounted integral to the valve rod **1108**, is utilized to bias the valve **1058**.

The fuel flow straightener **1056**, FIG. **10**, is located between the fuel poppet valve **1058** and the fuel piston **1054**. The fuel, after passing the fuel poppet valve **1058**, first passes through the straightening baffle **1056** and enters the center of a second baffle (not shown). The second baffle is comprised of two perforated spaced cylinders.

The pressure pick-up to the high pressure side of the fuel piston **1054**, as previously mentioned, is through the series of five holes **1112** (only two of which are shown) drilled in the tube **1110**. The tube **1110** is mounted on the side of the fuel gathering annulus **1134** away from the fuel inlet to the variable area altitude valve **1064**. The series of two baffles mentioned above reduce turbulance and local velocity heads created by turbulance, and gives an essentially true and steady pressure to the fuel piston **1054**.

The sensitivity equalizer **1052**, previously mentioned, is comprised of the small piston **1032** fed on one side through passage **1136** by air pressure from the high pressure side of the air piston **1034** and on the other side by pressure from a separate air bleed circuit **1036**. The forces from the sensitivity equalizer piston **1032** act on the free end **1028** of the Mach sensing bellows **1024** through the force pin **1138**. The purpose of the sensitivity equalizer **1052** is to equalize the sensitivity of velocity control mechanism **1044** with changes in altitude by preventing excessive travel of the shorting valve **1030** with a given velocity overshoot at low altitude (high air head), thereby permitting use of a sensitive high altitude (low air head) bellows. This results in increased sensitivity at high altitudes while holding a given maximum sea level sensitivity.

In addition to the small piston **1032**, the sensitivity equalizer **1052** is comprised of a spring **1140**, a force pin **1138**, and a piston sleeve **1142**. The bottom of the piston **1032** is fed by air pressure from the high side pressure of the air piston **1034**, and the top by the previously mentioned special bleed circuit **1036** and the spring **1140**. The force pin **1138** connects the bottom of the piston **1032** and the free end **1028** of the Mach sensing bellows **1024**.

Before the shorting valve **1030** opens, the air pressure acting on the bottom side of the sensitivity equalizer piston **1032** is higher than that operating on the top of the piston. However, the force pin **1138** is held against the free end **1028** of the Mach sensing bellows **1024** by the force of the spring **1140** acting through the piston **1032**. The entire shorting valve **1030**, Mach sensing bellows **1024**, and sensitivity equalizer assembly **1052** is supported by the two springs **1080** and **1140** at the ends thereof. All spring forces, including the spring force of the Mach sensing bellows **1024** are cancelled out so that the spring rates of both springs **1080** and **1140** and the Mach sensing bellows **1024** are added.

At low altitude, as the velocity of the missile **100** approaches 2,000 ft/sec from below, the Mach control mechanism **1044** and sensitivity equalizer **1052** are in a state of rest with all forces balanced and the shorting valve **1030** is closed. As the missile **100** enters the speed control range, the shorting valve **1030** opens slightly, dropping the pressure rapidly on the high pressure side of the air piston **1034**. As this pressure is dropped, the pressure on the bottom of the sensitivity equalizer piston **1032** is also dropped. The pressure on the top of the piston **1032**, combined with the spring pressure on the piston, tends to oppose further motion of the Mach sensing bellows **1024** and shorting valve **1030** and it reduces the travel of the shorting valve **1030** for a given increase in the ram-pressure atmospheric pressure ratio.

As the ram pressure atmospheric pressure ratio (Mach number) increases still further, the Mach sensing bellows **1024** opens the shorting valve **1030** still more, thus reducing the pressure on the high side of the air piston **1034** and the bottom of the sensitivity equalizer piston **1032** even more. The sensitivity equalizer spring **1140** and the pressure on the top of the piston **1032** oppose further opening of the shorting valve, with the rate of opening for the shorting valve, for a given increase in ram pressure atmospheric pressure ratio, being reduced even further. At velocities high above the speed control range, with the pressure on the bottom of the sensitivity equalizer piston **1032** at atmospheric (shorting valve **1030** open), the sensitivity equalizer **1052** applies a nearly constant force to the Mach sensing bellows **1024** and its effect is essentially the same as a higher spring rate in the Mach sensing bellows.

The result is that the sensitivity equalizer **1052** is out of the system, and the rate of travel of the Mach sensing bellows **1024** and shorting valve **1030**, for a given increase of ram pressure atmospheric pressure ratio, is nearly the same as without the sensitivity equalizer **1052** present. At velocities far below the design speed range (shorting valve **1030** full closed), the sensitivity equalizer **1052** does not affect the travel of the Mach sensing bellows **1024** for a given increase in ram pressure atmospheric pressure ratio. At high altitudes, when air pressures are low, the effect of the sensitivity equalizer **1052** is much reduced, and the travel of the Mach sensing bellows **1024** is dependent primarily upon the pressure ratio applied to the Mach sensing bellows.

The velocity sensing mechanism **1072** is mounted on a housing **1144** cast integral with the air piston assembly cover **1088**. The bellows **1014** is secured at one end **1146**, of the housing **1144**, and it is sealed by a brass plate soldered to the free end **1148** of the bellows **1014**. The free end **1148** of the bellows **1014** is connected to a variable area outlet bleed **1012** by a piano wire **1150**, and it positions the variable area outlet bleed **1012** in accordance with differential pressure signals generated by the previously mentioned temperature pick-up **1016** mounted in the ramjet diffuser **270**. Diffuser stagnation pressure is applied to the outside of the bellows **1014**, and a pressure generated by the bi-metallic controlled poppet valve **1020** and the downstream bleed **1022** is applied to the inner side of the bellows **1014.**

The variable outlet bleed **1012** comprises a spool type valve **1152** and a sleeve **1154** in which it operates. The spool valve **1152** is powered by the velocity sensing bellows **1014** by means of the piano wire **1150** linked to the bellows **1014.** The pressure from the bimetallic controlled poppet valve **1020** is led to each end of the spool **1152** to eliminate pressure unbalance on the valve ends. A corrected ram pressure is fed by tubes **868, 870, 872,** and **1156** to the center of the spool valve **1152.** This pressure acts on both inner faces of the spool valve to eliminate any pressure unbalance. The sleeve **1154** fits inside the velocity assembly casting **1144,** which is integral with the air piston housing cover. The sleeve **1154** is sealed against leakage within the housing by O rings **1158.**

The sleeve **1154** contains two sets of ports **1160** and **1162.** The inlet port **1160** consists of four radially drilled holes fed from an annulus **1164** in the velocity assembly housing **1144.** Ram pressure is fed to the annulus **1164** surrounding the sleeve inlet ports **1160** by means of the No. 65 bleed **1010,** and from the annulus **1164** to the inner bellows **1035** of the Mach sensing bellows **1024.** The outlet ports **1162** of the sleeve **1154** consists of two slots. These slots are cut in the sleeve **1154** in the same direction as the travel of the valve spool **1152.** These slots **1162** feed an annulus **1166** in the housing **1144** which is vented by passages **1168** and **1100** to static pressure. The design of the spool valve **1152,** sleeve **1154,** and ports **1160** and **1162** is such that the inlet ports **1160** are never covered by one end of the spool valve **1152,** while the other end of the spool valve **1152** varies the area of the outlet ports **1162** with the travel of the valve.

Ram air pressure is fed through the inlet ports **1160** of the sleeve **1154** to the spool valve **1152** between the lands of the valve and hence to the inner bellows **1035** of the Mach sensing bellows **1024.** The ram air is bled off between the lands of the velocity control spool valve **1152** and from the inner bellows **1035** of the Mach sensing bellows **1024** at a rate dependent upon the position of the spool valve **1152,** which determines the amount that the outlet port **1162** is open. The position of the valve **1152** is, in turn, dependent upon the pressure differential developed by the temperature pick-up **1016,** which is applied to the velocity sensing bellows **1014.**

Thus, on increasing the velocity, at a constant altitude, the temperature is increased. Higher temperatures increase the pressure ratio developed by the temperature sensing pick-up **1016** and applied to the velocity sensing bellows **1014.** Increased pressure applied to the velocity sensing bellows **1014** moves the bellows and spool valve **1152** in a direction to close the variable area bleed **1012.** Closing the bleed **1012** reduces the amount of air bled off from between the lands of the spool **1152** and the inner bellows **1035** of the Mach sensing bellows **1024.** Since the air flow through the No. 65 inlet bleed **1010** is essentially constant, reduction of the amount of air bled off by the variable area bleed **1012** increases the pressure applied to the inner bellows **1035** of the Mach sensing bellows **1024.**

At constant velocity and constant altitude, increasing the air temperature increases the pressure ratio produced by the temperature sensing pick-up **1016** and applied to the velocity sensing bellows **1014.** Increasing the pressure applied to the velocity sensing bellows **1014** causes the bellows and the spool valve **1152** to move so as to reduce the area of the variable area bleed **1012,** thus reducing the amount of air bled off from between the lands of the spool valve **1152** and the inner bellows **1035** of the Mach sensing bellows **1024.** At constant velocity, an increase in ambient temperature results in a decrease in Mach number. The action of the velocity control system is to prevent this decrease in Mach number from being seen by the Mach sensing bellows **1024** while the missile **100** is flying at a constant velocity.

The temperature pick-up **1016** shown in FIGS. **9A** and **73,** while not physically a part of the main fuel regulator **380,** is discussed with the main fuel regulator **380** as its operation is closely tied into the operation of the main regulator. The temperature pick-up housing **1168** is flanged to mount on the wall of the diffuser **270,** drilled for a series of bleeds **1022, 1170,** and **1172,** and the seat fitting **1174** of the poppet valve **1020.** A portion of the housing **1168,** projecting into the air stream in the diffuser **270** is ducted, by duct **1176,** to reduce the velocity head of the air flowing through it to essentially zero, resulting in maximum temperature and pressure recovery at the temperature pick-up **1016.** The location of the predetermined temperature pick-up **1016** in the diffuser **270** functions minimize error in stagnation temperature measurement. The temperature pick-up **1016** will operate satisfactorily at stagnation temperatures ranging from 160° to 530° F, and diffuser stagnation pressures ranging from 6 psia to 95 psia. The differential pressure generated will be a function of stagnation temperature.

The temperature sensing element **1018** in the temperature pick-up **1016** is a high response bi-metallic strip. The strip **1018** is mounted as a cantilever beam. A fixed end **1178** of the beam **1018** is clamped into a mounting machined in the duct of the temperature pick-up **1016.** A free end **1180** of the beam **1018** has a slotted hole cut near its edge, into which fits the upper end of a pick-up poppet valve stem **1182.**

The poppet valve seat **1174** is screwed into a hole **1184** in the pick-up housing **1168** directly below the end of the bi-metallic strip **1018.** It is secured in place by a lock nut **1186.** Adjustment of the pressure ratio acting across the velocity bellows **1014** is made by adjusting the position of the pick-up poppet valve seat **1174.** The poppet valve **1020** is a light weight, cone shaped valve connected to the bi-metallic **1018** by the piano wire **1182.** A fine mesh screen **1188** is located immediately below the poppet valve **1020** to prevent clogging of the bleeds in the velocity control bleed circuit. The outlet bleed **1172,** in series with the poppet valve **1020,** is vented to static pressure. The bleed **1022** is placed in the line from the poppet valve outlet to act as a surge preventer and permits smoother operation of the unit.

The pressure pick-up feeding the high pressure side of the velocity bellows **1014** by means of line **1190** also contains surge preventing bleed **1170.** The line **1190** is a pressure transmission line only; and the bleed **1170** in this line **1190** is merely a restriction to any rapid pressure changes.

The bi-metallic element **1018** is so mounted that increasing temperature tends to make the free end **1180** of the bi-metallic beam **1018** curl upwardly. As the free end **1180** of the bi-metallic beam **1018** is secured to the poppet valve **1020** through the piano wire **1182**, tension in the piano wire **1182** increases with increasing temperatures. This increased tension in the piano wire **1182** is balanced by the increased pressure drop across the poppet valve **1020** generated by the flow of air through the poppet valve. The design and configuration of the poppet valve **1020**, bi-metallic strip or beam **1018**, and bleed circuit is such that the pressure differential developed by the temperature pick-up **1016** is relatively independent of altitude (static pressure), diffuser pressure, and is dependent only upon the diffuser stagnation temperature.

The altitude sensing bellows **1060**, shown in FIG. **10**, is a spring loaded evacuated bellows which has one fixed end **1192** and one free end **1194**, which is connected to the variable area orifice valve servo **1062** by a piano wire link **1196**. Atmospheric pressure is fed to this bellows **1060**, which causes it to position the valve servo **1062**. With decreasing pressure (increasing altitude), the bellows **1060** increases in length at the rate of approximately 0.018 inch per inch of mercury pressure decrease.

The variable area orifice valve servo **1062** is a pressure balanced positioning mechanism consisting of a servo pilot valve **1198** and a servo follower **1200**. The servo pilot valve **1198** is a pressure balance spool valve, drilled longitudinally to equalize pressures at each end of the spool. The motion of this valve **1198** is a function of altitude, being moved by the piano wire link **1196** connected to the free end **1194** of the altitude sensing bellows **1060**. The servo pilot valve **1198** controls the flow of high pressure fuel through the servo follower **1200** to and from the top of the variable area orifice valve servo **1062**.

The variable orifice valve servo follower **1200** is a sleeve type follower with three lands on its outside surface. Lands **1202** and **1204** are located at each end of the follower **1200**, and the remaining land **1206** is located in the center thereof. These three lands **1202**, 1204 and **1206** form two annulus **1208** and **1210** around the servo follower **1200**, one of which carries regulator inlet fuel pressure (high pressure) and one of which carries servo operating pressure to the top of the variable area orifice valve **1064**.

The servo follower **1200** is connected to the top of the variable area orifice valve **1064** through a flexible linkage **1212**. The flexible linkage **1212** is used to prevent any misalignment of components to cause binding in a stable state. The altitude sensing bellows **1060** has caused the pilot valve **1198** to assume a given position. The servo follower **1200** has reacted to assume the equilibrium state, and there is no motion of the system or fluid flow through the assembly.

As the missile **100** climbs to altitude, the altitude sensing bellows **1060** expands and moves the servo pilot valve **1198** toward the variable area orifice valve **1064**. As the pilot valve **1198** moves, it uncovers a servo outlet port **1214**. As this port **1214** is uncovered, high pressure fuel flows from a high pressure fuel inlet port **1216**, through an annulus **1218** between the servo pilot valve **1198** and the servo follower **1200** and thence through the servo outlet port **1214** to the top of the variable area orifice valve **1064**.

As fuel flows to the top of the variable area orifice valve **1064**, the valve **1064** is moved to the left (closed position) against a spring **1220** and the regulator outlet pressure. The servo follower **1200**, being mechanically linked to the variable area orifice valve **1064**, moves to cover the servo outlet port **1214**. When the port **1214** is closed, fuel flow is cut off. The variable area orifice valve **1064** no longer moves, and a new equilibrium point is established.

When the missile **100** decreases altitude, the altitude sensing bellows **1060** decreases its length, moving the servo pilot valve **1198** away from the variable area orifice valve **1064**, and opening the servo outlet port **1214** to the overboard drain **990**, releasing fuel pressure from the top of the variable area orifice valve **1064**. Spring pressure plus regulator outlet pressure on the bottom of the variable area orifice valve **1064** causes this valve and the servo follower **1200** to move to the right until a new equilibrium point is reached.

The variable area orifice valve **1064** is of a piston type with a series of ports **1222** machined in the valve surface. The valve **1064** is fitted to a sleeve **1224** that fits into the main regulator body casting **1050**.

The valve **1064** is spring loaded to the full open position (low altitude position) until acted on by fuel pressure fed by the variable area orifice servo **1062** to oppose the spring force and regulator outlet pressure acting on the bottom of the valve **1064**. The port area must be coordinated with the altitude-travel relationship of the evacuated bellows-servo-altitude valve assembly.

The cast aluminum regulator outlet elbow **1120** bolts to the main regulator body casting **1050**, and provides support for the variable area orifice spring **1220** and the regulator outlet pressure pickup **1118**. The regulator outlet pressure pick-up **1118** consists of a pointed tube mounted parallel to fuel flow from the variable area orifice valve outlet **1120**. The tube **1118** has a series of holes **1226** along its length to pick up the regulator outlet static pressure. This pressure is fed to the low pressure side of the fuel piston **1054** through channel **1114** drilled in the mainbody casting **1050**, as previously mentioned.

In order to explain the overall operation of the main fuel regulator **380**, the following initial conditions will be assumed:

Standard day	
Velocity	1,900 feet per second
Altitude	Sea level
Static pressure	14.7 pounds per square inch
Static temperature	59° F
Mach number	1.702
Ram pressure	62.22 pounds per square inch
Ram to static pressure ratio	4.2325
Stagnation temperature	359.3° F
Temperature pick-up ΔP	7.2 inches Hg.

During the above conditions, the temperature pick-up **1016** impresses a differential pressure of 7.2 inches of mercury across the velocity sensing bellows **1014**, causing it to move the variable area bleed **1012** to such a position as to bleed sufficient pressure from the inner bellows **1035** of the Mach sensing bellows **1024** to lower the pressure ratio acting across the Mach sensing bellows **1024** to below a Mach number equal to 1.6 with a pressure ratio of ram to static of 3.8. The Mach sensing bellows **1024** has, however, moved the air piston shorting valve **1030** to a position such that it is near the position where it will open. The main regulator air piston differential pressure Δ P is such under these conditions to make the main fuel flow fully rich, giving the missile **100** excess thrust and causing it to accelerate.

If the missile **100** now accelerates to 2,000 ft/sec with no altitude or ambient temperature changes, the following conditions exist:

Velocity	2,000 feet per second
Altitude	Sea level
Static pressure	14.7 pounds per square inch
Static temperature	59° F
Mach number	1.792
Ram pressure	68.11 pounds per square inch
Ram to static pressure ratio	4.633
Stagnation temperature	391.8° F
Temperature pick-up ΔP	7.8 inches Hg.

As the missile velocity increases, the pressure differential generated by the temperature pick-up **1016** and applied across the velocity sensing bellows **1014** increases, causing the velocity sensing bellows **1014** to close the variable area bleed **1012.** This decreases the amount of pressure bled off the inner bellows **1035** of the Mach sensing bellows **1024.** At the same time, the ram pressure is increasing, thus increasing the pressure applied to the inner bellows **1035** of the Mach sensing bellows **1024** through the velocity control inlet bleed **1010.**

As the pressure applied to inner bellows **1035** of the Mach sensing bellows **1024** increases, the pressure ratio across the Mach sensing bellows **1024** increases since the static pressure applied to the outside of this Mach sensing bellows remains constant. At this pressure ratio increases, the Mach sensing bellows **1024** expands, moving the air piston shorting valve **1030** toward an open position. When the pressure ratio applied across the Mach sensing bellows **1024** reaches 3.8 (pressure ratio at a Mach number equal to 1.6), the shorting valve **1030** is on the verge of opening and any increase in pressure ratio opens the air piston shorting valve **1030** and shorts the high pressure side of the air piston **1034** to the low pressure side.

As the air piston differential pressure is decreased, the fuel metering linkage moves to reduce the flow of fuel through the main fuel regulator **380.** On reducing the fuel flow to the combustor **108,** there results a decrease in thrust so that the missile **100** no longer accelerates. Under normal flight conditions, when the main fuel regulator **380** goes lean (fuel flow reduces), this regulator will act in such a way that main fuel flow will be at some intermediate point between full rich and full lean, and sufficient thrust from the main combustor **376** will be provided to maintain the flight velocity of the missile **100** at 2,000 ft/sec.

With the missile **100** flying at sea level at a velocity of 2,000 ft/sec during a standard day, let it now be assumed that flight conditions are instantaneously changed to those of a proposed military cold day. For a proposed military cold day, flight conditions will be assumed as follows:

Altitude	Sea level
Ambient pressure	14.7 pounds per square inch
Ambient temperature	−22° F
Flight velocity	2,000 feet per second
Mach number	1.951
Stagnation temperature	310° F
Temperature pick-up ΔP	6.2 inches Hg.
Ram to static pressure ratio	5.3929
Ram pressure	79.3 pounds per square inch

It will be noted that for a cold day, with a flight velocity of 2,000 ft/sec, the flight Mach number as seen by the missile **100** is increased. This is due to the fact the velocity of sound in the atmosphere is dependent upon ambient temperature. In fact, the velocity of sound in the atmosphere is proportional to the square root of the absolute ambient temperature. As the Mach number is defined as the velocity of the air stream moving past an object (or the velocity of the object moving through the air), divided by the sonic velocity in undisturbed air, it can be seen that for a constant flight velocity, if the ambient air temperature is changed, that the Mach number will change.

At the new conditions, a larger mass of air flows through the combustor **108.** Denser air flows past the outside of the missile **100,** which results in an increase in drag. The main fuel regulator **380** acts in such a manner as to increase the fuel flow necessary to provide an increase in thrust to overcome the increase in drag and maintain velocity of the missile **100** constant. The decrease in ambient temperature results in a decrease in stagnation temperature at flight conditions. This decrease in stagnation temperature causes the bi-metallic element **1018** to exert less force on the pick-up poppet valve **1020,** which results in less pressure drop across the poppet valve **1020** and a lower pressure differential applied to the velocity sensing bellows **1014.**

The lower pressure differential applied across the velocity sensing bellows **1014** causes the variable area bleed **1012** to open further, thus bleeding off more of the ram pressure applied to the Mach sensing bellows **1024.** This results in the Mach sensing bellows **1024** seeing no change in applied pressure differential across it. The air piston shorting valve **1030** does not open further. An increase in ram pressure applied to the air piston inlet bleed **1228** results in a higher air piston differential pressure being applied to the air piston **1034,** which moves the fuel metering linkage in such a manner to cause an increase in pressure drop across the variable area orifice valve **1064,** resulting in an increase in fuel flow.

Let it now be assumed that the missile **100** is instantaneously raised to 40,000 feet altitude, on a cold day, with a flight velocity of 2,000 ft/sec. The flight conditions will now be assumed as follows:

Altitude	40,000 feet
Ambient pressure	2.722 pounds per square inch
Ambient temperature	−103° F
Flight velocity	2,000 feet per second
Mach number	2.160
Stagnation temperature	229.8° F
Temperature pick-up ΔP	5.2 inches Hg.
Ram to static pressure ratio	6.4931
Ram pressure	17.67 pounds per square inch

The stagnation temperature change with altitude results in a lower temperature pick-up Δ P being applied across the velocity sensing bellows **1014,** opening the variable bleed **1012** further to bleed off more of the ram pressure applied to the Mach sensing bellows **1024**, and lowering the pressure ratio seen by the Mach sensing bellows **1024** to its previous value. The lower ram pressure applied to the air piston inlet bleed **1228** results in a lower air piston Δ P, which causes the fuel metering linkage to move in such a manner as to reduce the pressure drop across the variable area orifice valve **1064**.

With the increase in altitude, the static pressure applied to the altitude sensing bellows **1060** has decreased. This decrease in pressure causes the altitude sensing bellows **1060** to increase in length, moving the servo pilot valve **1198** toward the variable area orifice valve **1064**. This action vents high pressure fuel to the top of the variable area orifice valve **1064**, moving it toward the closed position and moving the servo follower **1200** to close the follower ports **1214**, thus reducing fuel flow as a function of altitude. The correct pressure drop across the valve has already been determined by the fuel metering linkage.

The effects of acceleration of the missile **100** are primarily confined to the pilot and main fuel regulators **340** and **380**, respectively. Operation of the fuel and nitrogen shut-off valves **428** and **446**, respectively, which depend on boost acceleration of the missile **100** for operation has been discussed previously. The effect of acceleration of the missile **100** on the fuel in the inlet line **436** to the pump **532** was considered in establishing the regulated nitrogen pressure.

Minimizing of the acceleration effects on the pilot and main fuel regulators **340** and **380**, respectively, is accomplished by aligning the axes of the moving parts parallel to the longitudinal axis of the missile **100** where, after boost of the missile **100** has ended, minimum accelerations are expected. Furthermore, the design of the main fuel regulator **380** is such that longitudinal acceleration effects on the altitude valve control mechanisms cause an error in the opposite sense from the corresponding error induced in the pressure regulating linkages. This cancellation effect also occurs between the double bellows **1033** and **1035** of the Mach sensing bellows **1024** and the temperature controlled bellows linkages in the velocity control mechanism **1044**.

Squib activated time delay units **866** and **1230**, as shown in FIGS. 9A and **70**, may be used in the missile **100** to lower the fuel flows of the pilot fuel regulator **340** at separation of the missile **100** from the booster **500** to insure smooth ignition of the air-fuel mixture, and to lock the high pressure side of the main fuel regulator **380** to the low side before separation of the missile **100** from the booster **500** to reduce the main fuel flow to a minimum during boost of the missile **100**, respectively.

The squib activated time delay unit, such as **866** or **1230**, is a two position valve actuated by an electrically fired squib **1006**. These units are commonly used to control air flows and to change air pressures applied to various components in a system.

The squib activated time delay unit **866** or **1230** is comprised of a housing **988**, a piston valve **1002** so drilled as to permit free passage of air from near one end of the piston **1002** to the other end, a heavy spring **1232**, a housing cover **1234** which holds the spring **1232** in place, a piston actuating rod **1236**, and an actuating rod lever **1238**. A squib activated time delay unit **866** or **1230** in the "unfired position" is shown in FIG. **70**.

In the unfired position, the piston valve **1002** rides in a hole **1240** drilled through a housing partition **1242**. The piston valve **1002** is held by the actuating rod **1236** and actuating rod lever **1238** against the pressure of the spring **1232** so that air is free to flow from one end of the piston **1002** to the other by passage **1244** drilled in the piston **1002**. The end of the piston **1002**, upon which the spring **1232** acts, is of a larger diameter than the piston proper.

An O ring **1246** is placed around the piston **1002** beneath the enlarged end **1248** of the piston to seal against air leakage when the piston valve **1002** is closed. When the unit **866** or **1230** is in the unfired position, the actuating rod lever **1238** is lock wired to the body by means of a soft copper wire **1004**.

This wire **1004** extends through a chamber **1250** into which the squibs **1006** project and in which they fire. When the actuating rod lever **1238** is lock wired shut, it forces the actuating rod **1236** into the housing **988**, and opens the piston valve **1002** against the pressure of the spring **1232**. When a squib **1006**, mounted in the squib activated time delay unit **866** or **1230**, is fired, the soft copper wire **1004** is severed, releasing the actuating rod lever **1238**. The pressure of the spring **1232** against the piston valve **1002** forces the piston valve to the closed position against friction of the actuating rod **1236**. As the piston valve **1002** closes, the O ring **1246** seals against leakage around the hole **1240** in the partition **1242**.

The squib **1006**, used to activate these units **866** or **1230**, is electrically fired, and contains a small powder charge which shatters a copper cap (not shown) surrounding the squib **1006** upon firing. These squibs **1006** are potentially dangerous, and their two leads are grounded to each other when not installed in the missile **100**. A 4.5 volt battery supplies enough current to fire these units **866** or **1230**.

In the event it is not desired to use the squib activated time delay unit **1230**, it may be taken out of the main regulator air regulation circuit. It may be used to control the flow of regulated nitrogen pressure to the pilot regulator **340**.

Fuel flowmeters **460** and **462** can be incorporated in the fuel system of missile **100** to measure fuel flow through the pilot and main fuel regulators **340** and **380**, respectively, in order to determine proper operation of the missile fuel system. Information measured by these flowmeters **460** and **462** is fed into the missile telemetering system for transmission to the ground during aerial flight of the missile **100**.

The main fuel flowmeter **462** is mounted in the fuel outlet **1120** from the main regulator **380** and it measures fuel flow through the main regulator, while the pilot fuel flowmeter **460** is mounted in an outlet fuel line **1252** from the pilot regulator **340** and it measures the fuel flow through the pilot regulator.

The main and pilot flowmeters **462** and **460** are similar, with individual differences being principally in size of the bore which affect fuel flow versus frequency. As can best be seen in FIG. 72, each flowmeter **460** and **462** consists of a body casting **1254** containing a flowmeter bore **1256**, for fuel flow, a flow straightener (not shown), jeweled mountings **1258** and **1260**, a rotor-shaft assembly **1262**, a photoelectric cell **1264**, and a light source **1266**. A comparison of the bore sizes and frequency characteristics of these flowmeters is given below:

	Main Fuel Flowmeter	Pilot Fuel Flowmeter
Bore size, diameter	1.235 inches	0.896 inches
Fuel flow range	0–6.5 pounds per second	0–4.25 pounds per second
Frequency range	0–160 cps	0–245 cps

The bore **1256** and bearing supports **1258** and **1260** are streamlined to provide smooth flow through the flowmeter **460** or **462.** The straightener (not shown) is fitted to the inlet of the flowmeter **460** or **462** to insure smooth fuel flow therethrough.

The rotor-shaft assembly **1262** consists of two vanes **1268** mounted on a shaft **1270.** The entire assembly **1262** is blackened except for a small polished insert **1272** at one end of the shaft **1270.** This polished insert **1272** is wrapped around the rotor-shaft **1270,** and is so shaped that as the shaft **1270** rotates, the area passing under a given point varies sinusoidally at the frequency of the shaft rotation. The light source **1266** is so placed in the body casting **1254** as to shine on the polished insert **1272.** The light is then reflected to the photocell **1264** mounted in the same plane as the light source. The light source is a 4.5 volt 0.36 amp DC silica bulb. The bulb **1266** is mounted behind a sealed lens (not shown) which is so mounted as to cause the light from the bulb **1266** to shine on the polished insert **1272** in the shaft **1270.**

The photocell **1264** used in the flowmeters consists of a metal plate on which is deposited a thin layer of light-sensitive, conductive selenium. On top of this light sensitive layer of selenium is deposited a transparent layer of a special alloy. The iron base plate is sprayed with a non-corrosive metal and the entire unit is sealed with lacquer. This cell **1264** results in a direct transformation of light energy into electrical energy. The current produced varies directly as the intensity of the light reaching the photocell **1264.** The photocell **1264** is mounted in the flowmeter **460** or **462** behind a transparent lens (not shown) which is sealed against fuel leakage by an O ring. In practice, the photocell **1264** is held in place by a brass plunger fitting in a plastic screw plug. The brass plunger provides electrical contact with the photocell **1264** and mechanically holds it in contact with the lens.

In operation, fuel flow through the bore **1256** of the flowmeter **460** or **462** causes the rotor **1262** to rotate at a velocity dependent on the fuel flow rate. The light source **1266** delivers a light of constant intensity to the rotor insert **1272.** The constantly varying area of the insert **1272** presented to the light **1266** by the rotation of the shaft **1270** causes light of varying intensity to be reflected to the photocell **1264,** whose output varies in intensity. The photocell **1264** output is, therefore, a sinusoidally varying voltage, the frequency of which depends upon the rotational velocity of the shaft **1270.**

The output voltage of these flowmeters **460** and **462** is on the order of 10 to 30 millivolts. The input to each light bulb **1266** is 4.5 volts (DC) and 350 milliamperes. The expected frequency operating range for both fuel flowmeters **460** and **462,** respectively, is 10 to 250 cps.

The output frequency of the flowmeters **460** and **462** is directly proportional, with a high degree of accuracy, to the volume of fuel flowing. Frequency type measurements insure that noise and attenuation accompanying the telemetering signals during flight of the missile **100** do not destroy the accuracy of the readings. Both flowmeters **460** and **462** are constructed to be replaced by simple flow connectors in the event it is determined that fuel flow measurements are no longer deemed necessary.

The probe static relief valve **1048** is installed in the probe static line **1046** at the nose of the missile **100** to prevent damage to the Mach sensing bellows **1024** by accidental high probe static pressures.

This valve **1048,** FIG. **71,** is a ball type, spring loaded check valve, designed to open at between 4.5 psi and 7.5 psi above compartment pressure. The valve **1048** is installed to relieve any high pressure transients imposed upon the probe static line **1046** during the flight of the missile **100** and to prevent these high pressure transients from damaging the Mach sensing bellows **1024.** High pressure transients will be imposed on the probe static line **1046** whenever an oblique or plane shock wave passes over the probe static inlet **126.**

A T-fitting **1274** is installed in the line **502** between the nitrogen relief valve **452** and the inlet fitting **504** for the bladders **438,** as seen in FIG. **9B.** One side of this fitting **1274** leads to the turbine scoop **772.** The check valve **450** is positioned in the line **502** to allow free flow of air from the turbine scoop **772** to the bladders **438** when the scoop pressure is higher than the pressure in the nitrogen system. This check valve **450** is spring loaded to prevent flow of nitrogen from the nitrogen system to the turbine scoop **772.** This air connection, by lines **528** and **502,** permits air at the pressure in the diffuser **270** to pressurize the bladders **438** whenever the nitrogen system pressure falls below pressure in the diffuser **270.** For example, the pressure in the diffuser **270** would be higher than the nitrogen pressure during a low altitude intercept of the missile **100** after a long range "up and over" flight.

It is important that this check valve **450** be placed in the missile **100** with the valve body perpendicular to the principal axis of the missile **100,** with the hinge pin forward. When this valve **450** is in this position, acceleration forces during launching of the missile **100** will help hold the check valve **450** closed, and prevent loss of nitrogen.

Fuel injectors are provided as part of the fuel system to introduce the fuel into the air stream in a finely divided state, well mixed with the air to insure rapid and complete burning thereof.

As illustrated in FIGS. **9A, 31,** and **32,** fuel leaving the main and pilot regulators **380** and **340** first passes through the fuel flowmeters **462** and **460,** respectively, in the fuel passages **1276** and **1252** to the turbine air intake strut **424.** The air intake strut **424** is secured diagonally across the diffuser **270,** in the forward portion of the center body **106** of the missile **100.** Channels **1278** and **1280** in the forward side of the strut conduct air from the diffuser **270** to the fuel turbine pump and hydraulic turbine **440** and **1282,** respectively. The aft side of the strut **424** to the fuel turbine pump **440** is divided into two channels **422** and **420** which carry main and pilot fuel to the fuel delivery tubes **1276** and **1252,** respectively.

The fuel delivery tubes **164** and **166** are concentric tubes mounted on the center line or longitudinal axis of the missile **100.** The forward ends of these tubes **164** and **166** are connected with the passages **420** and **422** of the air intake strut **424**. The pilot and main fuel delivery tubes **164** and **166** are made of aluminum. The main fuel delivery tube **166** is mounted inside the pilot fuel delivery tube **164** and is arranged concentric with it. The forward ends of both tubes **164** and **166** fit into the aft side of the air intake strut **424** and are sealed with **0** rings (not shown).

The pilot fuel tube **164** terminates in the forward end of a pilot manifold hub **1284**. The terminal ends of both tubes **164** and **166** are sealed with O rings **1286** and **1288**, respectively. The tubes **164** and **166** are held in place longitudinally by the pilot manifold hub **1284** which is supported by shroud assembly **332** and the air intake strut **424** which is supported in the wall of the diffuser **270**. The aft end of the pilot manifold hub **1284** is tapered to a reduced diameter and extends to the forward end of the main fuel distribution valve **384**, where it terminates and is sealed by an O ring **1290**, shown in FIG. 34.

As seen in FIG. 32, four struts **342** of aluminum tubing are utilized to secure the pilot injector manifold ring **344** to the pilot manifold hub **1284**. These struts **342** are spaced 90° apart around the hub **1284** and are welded thereto. The manifold injector ring **344**, as previously mentioned, is made of aluminum tubing formed in a circle, drilled for the entry of the struts **342**, and it is welded thereto. Sixteen fittings **1292**, spaced 22½° apart, are welded to the forward side of the injector ring **344**, for mounting of the fuel injectors **330**. The forward end of these fittings **1292** are threaded so that the pilot injectors **330** can be screwed and lock wired thereon.

In FIG. 74, each of the pilot fuel injectors **330** proper is of a spring loaded pintle type. These injectors **330** are screwed directly to the injector fittings **1292** which, as previously indicated, are welded to the forward side of the manifold ring **344**. The body of each injector **330** is formed of a cylindrical piece of stainless steel.

One end of the body of each injector **330** is tapped with threads **1298** for securing it to the injector fittings **1292** on the manifold ring **344**. A sleeve **1294**, with a shoulder **1296**, is pressed into the body at the end opposite the threads **1298**. The outer face of the sleeve **1294** is machined with a seat **1300** for a pintle valve **1302**. The sleeve **1294** has holes **1304** drilled from its outside to inside surfaces to permit passage of fuel through the sleeve **1294**. This sleeve **1294** serves as a guide for the pintle valve **1302**; a support point for a spring **1306** which loads the pintle valve **1302**; and as the seat for the pintle valve **1302**.

The pintle valve **1302** is made of stainless steel and includes a rod threaded at one end. The opposite end of the pintle valve **1302** is machined with a valve disc **1308**, which tapers to a point at the extreme end. The pintle valve **1302** has two lands **1310** machined on it which guide the pintle valve **1302** in the sleeve **1294**. The pintle valve **1302** is inserted into the valve sleeve **1294** and held in place by the load of spring **1306** acting against a shouldered adjustment nut **1312** screwed to the end of the shaft **1314**. The shoulder nut **1312** is locked in place by a small lock nut **1316**.

The pressure drop across the injector **330** is adjusted by adjusting the spring force on the pintle valve **1302** by means of the shoulder nut **1312**. It is to be noted that the units are designed so that fuel flow rates, at given pressure drops, for each injector **330** must agree within ± 5 percent. The pressure drop across the injector **330** varies from 15 psi to 160 psi, depending on the rate of fuel flow. When the injector **330** is passing fuel, fuel pressure, acting on the inner face of the valve disc **1308**, causes the pintle valve **1302** to open. As the fuel leaves the injector **330**, it is broken up into a very fine, conical, fog like spray. Thus, the pilot fuel is injected against the air stream by the sixteen injectors **330** mounted on the injector ring **344**. Combustion of the pilot fuel is initiated by means of the previously mentioned modified aircraft type spark plug or igniter **1008** which is supplied with high voltage by a conventional vibrator-induction coil combination.

As previously mentioned, the aft end of the pilot manifold hub **1284** tapers to a reduced diameter and extends aft for a fixed distance and then terminates in the main fuel distribution valve **384**. It is sealed by the **0** ring **1290**.

In FIGS. **31, 32,** and **35,** the main fuel distribution valve **384** is a sliding piston variable area orifice valve made of stainless steel. It has a valve sleeve **1318**, with four flats **1320** spaced 90° apart and milled along its outside surface. The aft end of hub **1284** fits into the forward end of sleeve **1318**. Four holes **1322** are drilled through the sleeve **1318** on the centerline of each flat **1320**.

The moving part of the valve **384** consists of a piston **1324** which is closed at one end. Four rows of holes, each row containing four holes **1326**, are drilled through the piston **1324** to match with the four rows of holes **1322** drilled through valve sleeve **1318**. A slot (not shown) machined to cooperate with a pin (not shown) inserted in the sleeve **1318** prevents the piston **1324** from rotating and causing misalignment of the ports **1326** and **1322** in the piston **1324** and sleeve **1318**, respectively. The closed end of the piston **1324** bears against a valve spring **1328**, which is housed in the aft section **1330** of the valve **384**. The aft section **1330** contains an adjustable stop **1332** which positions the piston **1324** in its open position, and a back pressure vent **1334** connected to one of the holes **1322** in the valve sleeve **1318** to vent the pressure of the injectors **386** to the back side of the piston **1324**.

A fairing **1336** is bolted to the after side of the aft section **1330** to give the valve **384** to clean aerodynamic surface. The piston **1324** is held in the valve sleeve **1318** against spring pressure by a snap ring **1338**. When no fuel pressure is applied to valve **384**, this valve is held in the closed position against the snap ring **1338** by the valve spring **1328**. When fuel pressure is applied to the valve **384** and reaches 22 psi, the piston **1324** has moved enough to cause the ports **1326** in the piston **1324** to uncover the ports **1322** in the sleeve **1318**, thereby permitting fuel flow through the ports **1322** to the injectors **386**. The maximum pressure drop across the valve **384** is 25 psi.

The fuel from the fuel distribution valve **384** passes to four struts **1340** bolted to the flats **1320** of the valve **384**. Each strut **1340** contains four drilled passages **1342** which match with the drilled ports **1322** of the main fuel distribution valve sleeve **1318**. After passing through the strut **1340**, the fuel enters a main fuel manifold **1344**, which contains entrance holes (not shown) matching the passages **1342** in the struts **1340**. The struts **1340** and manifold sections **1346** are welded together at their mating faces, as shown at **1348**. The main fuel distribution manifold **1344** is manufactured in four 90° sections **1346** from aluminum.

Four equally spaced holes **1350** are drilled in the aft side of each manifold section **1346** for mounting injector tubes **1352.** Passages **1354,** which connect the holes **1350** with the holes matched to the strut passages **1342,** are drilled parallel with the surfaces of the manifold sections **1346** before the manifold **1344** is rolled to circular shape. Both ends of each quarter section **1346** of the manifold **1344** are bolted to a "T" bracket **1356** which secures the manifold **1344** in the forward end **388** of the combustor central can assembly **370.**

Further support for the manifold **1344** is provided by the inner ends of the struts **1340** bolting to the flats **1320** on the main fuel distributing valve sleeve **1318.** In each of the equally spaced holes **1350** drilled on the aft side of the manifold sections **1346,** an aluminum tubing **1352** is welded. The injector end of each tube **1352** is bent outward to form an injection circle. The injector end of each tube **1352** is flared to a reduced diameter for mounting the injectors **386.**

The injector body **1358,** FIG. **75,** is a cylinder. A shoulder **1360** formed by the intersection of the two internal diameters is beveled to form a seat for a piston valve **1362.** Two rows of holes **1364** and **1366** are located downstream from this shoulder **1360.** Both rows of holes **1364** and **1366** contain six holes which are drilled radially through the injector cylinder **1358.** These holes **1364** and **1366** are used for the fuel exit ports. The rows of holes or ports **1364** and **1366** are uncovered, in turn, by the piston valve **1362** operating in the injector cylinder **1358.**

Two grooves **1368** and **1370** are machined around the outside of the inlet end of the injector cylinder **1358.** The groove **1368,** nearest the inlet end of the injector cylinder **1358,** contains an O ring (not shown) to seal against fuel leakage between the cylinder **1358** and the injector tube **1352;** while the inboard groove **1370** is used to secure the injector **386** to the injector tube **1352.**

The injector tube **1352** has two slots (not shown) cut near the end perpendicular to the tube axis which line up with the inboard groove **1370** in the injector cylinder **1358.** A lock wire (not shown) wrapped around the end of the tube **1352** engages both the slot and the groove **1370** and secures the injector **386** in place. Both ends of the piston **1362** are beveled to match with the valve seat **1360.** The piston **1362** is held in the closed position by an injector spring **1372,** which is secured in the injector cylinder **1358** with a snap ring **1374** and spring retaining washer **1376.**

The injector spring **1372** is designed to give a pressure drop across the injector **386** of from 10 to 25 psi, depending on fuel flow. The inlet pressure of the injector **386** acts against the piston **1362,** and moves it toward the open position, uncovering the row of small ports **1364.** A higher fuel flow imposes more pressure on the piston **1364** and moves it to uncover the row of large ports **1366** when high fuel flows are demanded. This low pressure injector **386** is provided in the main fuel system primarily to prevent boiling of the fuel in the injector tubes **1352** and manifold ring **1344** at high altitudes.

As illustrated in FIGS. **15** through **19,** the hydraulic system **220** for the missile **100** is an auxiliary power supply used in conjunction with the guidance control system **214.** The signal inputs to the hydraulic system **220** consist of differential voltages applied to torque motors **1378, 1379, 1380,** and **1381** of the hydraulic system by the guidance control system **214.** The output of the hydraulic system **220** is used to operate wing actuators **1382, 1383, 1384,** and **1385** which, through the wing linkages, in turn, operate the wings **112, 113, 114,** and **115.** The hydraulic system **220,** together with the guidance control system **214,** forms an electrohydraulic servomechanism to position the pairs of missile wings **112, 114** and **113, 115.** The hydraulic system **220** is designed to operate at **1750** psi.

The hydraulic system **220** is a closed loop hydraulic system. It consists primarily of an air turbine **1282** which drives a hydraulic pump **1390,** transfer valves **1392, 1393, 1394,** and **1395,** a sump **1396,** and the wing actuators **1382, 1383, 1384,** and **1385.** Other auxiliary equipment, such as filters, check valves, accumulators, has been added to make the hydraulic system **220** more practicable and workable. A relatively independent sub-system, the wing lock system **1398,** has been added to hydraulically unlock the wings **112** through **115** at the separation of the missile **100** from its booster **500,** and to signal wind lock retraction to the guidance control system **214** by a pressure operated switch in the wing lock subsystem **1398.**

In order to facilitate missile testing, provisions can be made in the hydraulic system to operate the system with an external source of hydraulic power. It is not necessary to disrupt any missile hydraulic plumbing in order to apply external hydraulic power. External hydraulic power can also be applied to the wing lock subsystem **1398.** Under these conditions, the wing lock subsystem **1398** is isolated from the remainder of the hydraulic system by check valves.

All hydraulic tubing connecting various components on the high pressure side of the system is constructed of corrosion resistant steel. All low pressure tubing is manufactured of aluminum. Tubing and components are connected by the use of standard fittings.

A hydraulic turbine-pump assembly **1281** is the power source for this system **220.** The pump **1390** is driven by the high speed single stage impulse turbine **1282,** which is powered by diffuser air from the air intake strut **774.** The pump **1390** is driven by the turbine **1282** through a planetary reduction gear assembly **1400** with a reduction ratio of 6.2 to 1. The pump **1390** is a constant displacement axial stroke piston type pump, rated at 20.3 gal/min at a nominal pressure of 1750 psi.

Pump pressure regulation is obtained by means of a movable nozzle plate on the air turbine inlet. This nozzle plate is postioned through a control linkage by the pump outlet pressure, the position of the nozzle plate determining the power input to the pump **1390,** speed of the pump and the pump outlet pressure. The throttle control linkage is spring loaded in such a manner as to hold the throttle full open until the pump outlet pressure approaches 1750 psi. When the pump outlet pressure reaches 1750 psi, hydraulic pressure causes the throttle plate to move toward the closed position, reducing the pump speed and the quantity of oil pumped. When an oil demand occurs, a reduction in system pressure takes place, opening the turbine throttle and increasing the pump output.

In order to provide constant pressure in the system, absorb pressure peaks, and provide a reserve of high pressure oil for peak demands, two hydraulic accumulators **122** and **1402** are included in the high pressure side of the system. One accumulator **122,** a **198** cubic inch accumulator, is mounted in the diffuser inner body. This accumulator carries a nitrogen precharge of 700 psia, and acts primarily as an oil reservoir to supply oil during periods of high oil demand. The second accumulator **1402**, a 60 cubic inch accumulator, is mounted near the pump outlet in the missile hydraulic section. This accumulator **1402** carries a 1,000 psia nitrogen precharge and acts primarily to smooth out high pressure peaks.

In the missile system, each wing **112**, **113**, **114**, or **115** is individually controlled. Thus, for each wing an actuator **1382**, **1383**, **1384**, or **1385** and a hydraulic control valve **1392**, **1393**, **1394** or **1395** is necessary to control the wing. The control valves **1392** through **1395** are balanced spindle linear flow type valves which control oil flow to the actuators **1382** through **1385**. The position of the valve spindles is controlled by the previously mentioned torque motors **1378** through **1381**, which are of the linear displacement, electromagnetic type. Thus, in the design range the output of the transfer valve-torque motor combinations, oil flow is linear with differential current applied to the torque motor coils.

The transfer valve-torque motor combinations control the flow of hydraulic oil to the wing actuators **1382** through **1385**, which is the power dissipating portion of the hydraulic system **220**. The actuators **1382** through **1385** consist of a hydraulic piston, mounted in an oil tight cylinder. Each end of the actuator is connected to one side of one of the transfer valves **1392** through **1395**. A piston rod **1386**, extends through one end of the actuators **1382** through **1385** and is connected to the wing bell crank **329** by bolt **1388**.

All oil entering the transfer valves **1392** through **1395** is passed through a **10** micron filter. Two filters **1404** and **1406** are used, with each filtering the oil to two pairs of transfer valves **1392**, **1393**, and **1394**, 1395, respectively.

Low pressure oil from the actuators **1382** through **1385** after passing through the transfer valves **1392** through **1395**, is fed to the missile sump **1396**. The sump **1396** is a cylindrical tank containing a nitrogen bladder which is precharged to **20** psia. The sump **1396** acts as a reservoir to store oil necessary for charging the high pressure accumulators **122** and **1402**. It provides a pressure head to the inlet side of the hydraulic pump **1390**; a cooling volume for the oil after passing through the hydraulic system; and oil to make up for system leakage. The sump **1396** is fitted with a low pressure oil gauge **1408** and a small charging line **1410**. When the hydraulic system **220** is once bled and charged, it is maintained under pressure by the nitrogen precharge on the sump bladder **1412**. Leakage from the system **220** can be made up by precharging the sump **1396** through the sump charging line **1410**.

Prior to flight of the missile, the sump **1396** is charged to a pressure of approximately 100 psia. Immediately prior to firing, the hydraulic system sump pressure is checked, and the hydraulic system **220** is recharged if the sump pressure is **65** psia or lower at the time of firing.

The hydraulic turbine-pump assembly **1281** is the power source of the hydraulic system. The rotor of turbine **1282**, illustrated in detail in FIG. **76**, revolves at a very high speed, and consequently, has to be geared down through a reduction gear assembly **1400** to the lower pump operating speeds. A housing **1414** for the turbine assembly **1282** and the reduction gear assembly **1400** is made of an aluminum alloy casting. It is machined internally to provide a casing for the turbine assembly **1282** and a base and cover for the reduction gear assembly **1400**. The forward end of the housing **1414** is secured to the outlet **1416** of the turbine air intake strut **774** by a plurality of bolts. The after end provides a base for the hydraulic pump **1390**.

The turbine **1282** is a single stage, axial flow impulse type. A built-up turbine wheel **1418** is constructed of a disc of aluminum with **36** slots **1420** milled in the circumference. Steel blades **1422** are staked in these slots **1420**. This wheel is carefully balanced and spin-tested to 50,000 rpm. The wheel **1418** is secured to a tapered section **1424** of a shaft **1426** by a lock ring **1428**. This lock ring **1428** engages two milled slots in the face of the wheel **1418** and a flatened surface of the shaft **1426**. Lock nuts **1430** hold the lock ring **1428** and wheel **1418** in position axially.

A nozzle plate **1432** for the trubine assembly **1282** is made similar to the trubine wheel **1418**. Sixteen blades **1434**, forming nozzles **1435**, are machined in an aluminum disc **1436**. This disc fits inside the housing **1414** and it is locked in place by a pin (not shown) and a stainless steel ring **1438** bolted to the housing **1414**. A heavy duty, ball type, thrust bearing **1440** is fitted in an annular groove **1442** in the forward face of the nozzle plate **1432** to help support a throttle plate **1444**.

The throttle plate **1444** is provided to control the volume of air to the turbine wheel **1418**, which, in turn, controls the outlet pressure of the pump **1390** and the oil flow. Plate **1444** is a disc of aluminum. Slots **1446** are machined in the outer edge of the plate **1444** to coincide with the inlets of the nozzles **1435**. The forward race **1448** of the thrust bearing **1440** is fitted into an annular groove **1450** in the after face of the throttle plate **1444**.

An oilite bushing **1452**, which is located between a shaft **1454** which is, in turn, bolted to the nozzle plate **1432** and a shell **1456** which is, in turn, bolted to the throttle plate **1444**, provides a radial bearing surface. One thirty-second of a revolution of the throttle plate **1444** changes the opening of the throttle plate from a fully opened to a fully closed position. The position of the throttle plate **1444** is controlled by a pump control assembly **1458**.

In order to protect the turbine **1418** from damage by foreign matter, stainless steel screens **1460** and **1462** are fitted to the air inlet and outlet of the turbine assembly **1282**.

A bearing housing **1464**, formed of cold rolled steel, is fitted into and secured to the outer housing **1414** by bolts **1466**. It provides support for the turbine shaft **1426** by utilizing two rows of ball bearings **1468**, separated by a carbon face oil-seal assembly **1470**. The bearings **1468**, oil-seal **1470**, a spacer **1472** and a pinion gear **1474** are fitted over the shaft **1426** and held against a shoulder **1476** by lock nuts **1478**. This assembly fits inside the bearing housing **1464** and is held in place by a snap ring **1480** bearing against the outer race of the after bearing **1468**. An end cap **1482**, bolted to the bearing housing **1464**, holds the assembly in position.

A pinion gear **1474**, keyed to the shaft **1426**, meshes with three idler gears **1484**. The idler gears **1484**, fitted with needle bearings **1486**, rotate on shafts **1488** which are held in drilled holes **1490** in the bearing housing

1464 by lock screws **1492.** The idler gears **1484** mesh with and drive a bell gear **1494.** The bell gear **1494** is made up of a ring gear **1496** fitted and pinned to a bell shaped body **1498.** The body **1498** is machined with a stub shaft **1500** inside the bell and a male spline drive shaft **1502** on the outside thereof.

Two rows of ball bearings **1504** fit over the stub **1500** and inside the bearing housing **1464.** These bearings **1504** are secured in position by snap rings **1506** and **1508** and an end cap **1510** bolted to the bearing housing **1464.** By means of the 15 tooth pinion gear **1474,** 39 tooth idler gears **1484,** and a 93 tooth bell gear **1494,** a speed reduction of 6.2 to 1 is obtained and the rotation is chagned from counterclockwise to clockwise.

An inductance type electrical pick-up **1512** is mounted in the outer housing **1414** near the bell gear **1494.** This pick-up **1512** is used to determine the pump speed in missile testing and flight telemetering.

The hydraulic pump **1390,** as best seen in FIGS. **77,** 78, and **79,** is a seven piston positive displacement type pump. Its rated capacity is 20 gal/min at 1,750 psi discharge pressure at 4,000 rpm.

A housing **1514** for the pump **1390** is constructed of two machined aluminum alloy sections **1516** and **1518.** These sections **1516** and **1518** are secured together by bolts **1520** and are sealed with an O ring **1522.** The forward casting **1516** is machined to house a stationary beryllium copper cam plate **1524.** The cam plate **1524** is secured with a dowel pin (not shown) at an angle of 16.4° from the perpendicular of the pump axis. A morganite bushing **1526,** doweled to the casting **1516,** is the forward bearing for the rotor **1548.** An oil seal **1528** prevents hydraulic oil leakage from the pump **1390** to the reduction gear assembly **1400.** A snap ring **1530** locks the oil seal **1528** and bushing **1526** in the casting **1516.**

The after section **1518** of the housing **1514** is machined internally to receive a chrome steel port plate **1532,** a spider washer **1534** and a large morganite bearing **1536.** The port plate **1532** and morganite bearing **1536** are dowled in place and held in the after section **1518** with a snap ring **1538.** Four bosses **1540, 1542,** 1544 and **1546** are cast to the end of the after section **1518.** The largest of these bosses, namely boss **1540,** is the low pressure inlet to the pump **1390;** while the next larger boss **1542** is the pump high pressure outlet connection. The two small bosses **1544** and **1546** are high and low pressure taps for use with the turbine control assembly **1458.**

The rotor **1548** carries seven pistons **1550,** only one of which is shown, in cylinders **1552,** which are evenly spaced around a circle concentric with the rotor drive shaft **1554.** These cylinders **1552** are fitted with silver carbon bushings **1556** in which the pistons **1550** move. The closed ends of the pistons **1550** are machined with a ball **1558** which is received in socketed slippers **1560** riding on cam plate **1524.** A rotating auxiliary cam plate **1562** and springs **1564** mounted within the pistons **1550** hold the slippers **1560** against the cam plate **1524.** The auxiliary cam plate **1562** is mounted on the rotor shaft **1554** by means of a spherical sleeve **1566,** which is loaded by a spring **1568** to hold it aft against a flange **1570** on the slippers **1560.** The springs **1564** are held in the rotor body **1548** and are prevented from rubbing on the port plate **1532** by spring retainers **1572** fitted in the end of the rotor cylinders **1552.**

Small holes **1574** and **1576** drilled through the balls **1558** and the slippers **1560** provide forced lubrication to the bearing surface on the stationary cam plate **1524** during the piston pumping cycle. The port end of the rotor **1548** is ground and heavily plated with silver to provide a pressure seal against the port plate **1532.** The port plate **1532** is a chrome steel disc, and it contains two kidney shaped ports **1578** and **1580** which are machined concentric with a center hole **1582.** One of these ports **1578** serves as the pump inlet port, while the other port **1580** serves as the pump outlet port. The center hole **1582** in the port plate **1532** provides a passage to the pump inlet port **1540** to vent the internal pump leakage. The rotor **1548** is drilled with three passages **1584** to vent the cam plate end of the pump housing **1518** to the center hole **1582** of the port plate **1532.**

When the pump **1390** is operating, the rotor **1548** rotates, carrying with it the seven pistons **1550,** the auxiliary cam plate **1562,** and slippers **1560.** The slippers **1560** are held against the stationary cam plates **1524** by the piston springs **1564** and the auxiliary cam plates **1562.** As the rotor **1548** rotates a given piston **1550** is moved axially in its cylinder bushing **1556** by the action of the stationary cam plates **1524.** As the piston **1550** moves away from the port plate **1532,** the open end of its cylinder **1552** is aligned with the kidney shaped inlet port **1578.** When the piston **1550** reaches its extreme travel, it passes the plate area between the kidney ports **1578** and **1580.** As the end of the cylinder **1552** aligns with the secondary kidney port **1580** (the outlet port), the piston **1550** is caused to move toward the port plate **1532** by the stationary cam plate **1524,** and it pumps oil into the outlet port **1580.** During this stroke, a small amount of oil is pumped through the small holes **1574** and **1576** in the balls **1558** and the slipper **1560,** respectively, to lubricate the stationary cam plate **1524.**

When the piston **1550** reaches the extreme end of its discharge stroke, the cylinder **1552** is covered by the plate **1532** between the kidney ports **1580** and **1578.** As the rotor **1548** rotates further, the cylinder **1552** again aligns with the inlet port **1578** and the stationary cam plate **1524** again and causes the piston **1550** to move away from the port plate **1523,** starting a new pumping cycle.

The pump control assembly **1458,** as best seen in FIGS. **15, 80,** and **81,** regulates the discharge pressure of the pump **1390** by actuating the throttle plate **1444,** thereby controlling the volume of air to the turbine wheel. The assembly **1458** is doweled and bolted to the turbine housing **1414** in such a manner that an arm **1586** on the control assembly **1458** actuates an arm (not shown) on the throttle plate **1444** by means of a rod **1588.**

Oil from the pump discharge high pressure boss or top **1546** enters the assembly **1458** through a small porex filter **1590** and acts on the top of a small spring loaded servo piston **1592.** The servo piston **1592** is held in the closed position by a compression spring **1594** acting on its lower end. This spring **1594** is used to adjust the pump discharge pressure. As the hydraulic pressure on the top of the servo piston **1592** overcomes the pressure of the spring **1594,** the servo piston **1592** is displaced and it uncovers a port **1596** in the servo piston sleeve **1598.** This allows oil to flow through passage **1600** in the body **1602** of assembly **1458** to a spring loaded control piston **1604.**

A hole **1606** drilled in the control piston **1604** bleeds oil from the top of the control piston to a control linkage area, and through a damping bleed **1608** to the pump inlet **1540** by way of the boss **1544.** Thus, the pressure applied to the control piston **1604** is determined by the bleed circuit formed by the opening of the servo piston **1592** and the hole **1606** in the control piston **1604.** Pressure applied to the top of the control piston **1604** moves the control piston against spring pressure and the throttle plate **1444.**

When no pressure is applied by the servo piston **1592,** a control piston spring **1612** moves the control piston **1604** and throttle linkage **1610** to open the throttle plate **1444** and pass more air to the turbine wheel **1418.** Motion of the control piston **1604** is applied to the throttle plate **1444** through a crank arm **1614.** Crank arm **1614** is hinged to the control piston **1604** and it is slidably received on a crankshaft **1616.** Movement of the hinged end of the crank arm **1614** rotates the crankshaft **1616,** which, in turn, rotates the throttle plate control arm **1586.** The throttle plate **1444** is secured to the control arm **1586** by a rod **1588,** the ends of which are provided with ball and socket joints **1618.** When the control piston **1604** is moved its full stroke, the throttle plate **1444** revolves from a full open to a full closed position.

The purpose of the hydraulic sump **1396, FIG. 82,** is threefold, namely, to provide oil for accumulator storage and system leakage; to provide pressurized oil to the inlet of pump **1390** to prevent cavitation thereof; and to provide a reservoir for cooling oil.

The cylindrical shell **1620** is sealed at one end by an end plate **1622.** The end plate **1622** is drilled and tapped for a system supply line **1624,** a system drain line **1626,** three return lines **1628, 1630,** andd **1632,** and an oil precharge line **1410.**

The opposite end of the cylinder **1620** is sealed by bladder support ring **1634** which is affixed to shell **1620** of the sump **1396.** The bladder cover plate **1636** is held in place by a threaded ring **1638** screwed into the bladder support **1634.** The cover plate **1636** is drilled and tapped to receive a high pressure air valve **1640,** which is used to precharge the bladder **1412** with nitrogen pressure. The high pressure air valve **1640** is a double seal valve. One seal of the valve is a spring loaded stem and disc, which is similar to a conventional tire type air valve. The other seal of the valve is a metal to metal seal which is seated manually with a wrench inside the sump **1396.**

A baffle plate **1642,** containing a plurality of holes **1644,** is located near end plate **1622.** This baffle plate **1642** serves as a bladder stop; prevents the bladder **1412** from expanding the full length of the sump **1396;** and maintains a reservoir of oil for cooling.

The bladder **1412,** contained in the sump **1396,** is made of synthetic rubber and it is formed in the shape of a bellows with one open end. The neck **1646** of the open end of the bladder **1412** is seated in the bladder support **1634,** with the bladder cover **1636** sealing the bladder. The opposite end of the bladder **1412** is free. The bladder **1412** will expand longitudinally when pressurized. The expansion and collapsing of the bladder is controlled by the variation in bladder wall thickness. The bladder **1412** is limited to a working volume by the baffle plate **1642.**

To charge the sump **1396** for use, the bladder **1412** is charged first with nitrogen to a pressure of 20 psia with the oil side open to atmosphere by a vent **1648.** This will cause the bladder **1412** to expand to the baffle plate **1642.** The system is then charged with oil through the oil precharge line **1410** to 100 psia. This will force oil into the sump **1396** and compress the bladder **1412** until the nitrogen pressure is equal to the oil charge pressure. When the system pressure is at its maximum pressure of 1750 psia, oil will be removed from the sump **1396** and stored in the two accumulators **122** and **1402.** This allows a reserve storage of oil to compensate for system leakage.

In the hydraulic system **220,** two high pressure accumulators are used. These accumulators **122** and **1402** are used to supply oil for high energy storage to meet peak flow demands, and to prevent pressure surges due to rapid change in oil flow demand and pump output pressure fluctuations.

Accumulator **122,** is located in the inner body **120** of missile **100** as best seen in **FIG. 7.** This accumulator has a nitrogen precharge pressure of **700** psia on it, and it is used primarily for delivery of oil at high flow demands, especially at high altitudes. The second high pressure accumulator **1402** is located in compartment **220** just aft of bulkhead **308.** This accumulator **1402** carries a nitrogen precharge pressure of 1,000 psia. Due to its proximity to the hydraulic pump outlet **1542,** this accumulator **1402** acts primarily to smooth the pressure fluctuations of the hydraulic system.

The accumulators **122** and **1402** are identical in construction except for the dimensions of the shell **1650,** bladder **1652** and bladder cover plate **1654.** Each accumulator **122** or **1402** is comprised of a spherical shell **1650** to which there is affixed a fitting **1656** for connection with an oil line **1658.** A perforated baffle plate **1660** is press fitted into the base of the oil connection fitting **1656** to support plug **1662** which is attached to the bladder **1652** when no oil is in the accumulator **122** or **1402.** Also affixed to the shell **1650** is a boss **1664** containing the bladder seat **1666.** This boss **1664** is threaded to receive a bladder cover securing ring **1668.** The bladder **1652** is a synthetic rubber sphere with a greater wall thickness at the precharge side and a smaller wall thickness at the oil line side thereof. This difference in wall thickness controls the collapsing action of the bladder when the accumulator is charged with oil.

A series of small buttons **1670** are molded on the lower half of the bladder **1652,** on the oil side, to prevent the bladder **1652** from sealing against the shell **1650** and trapping pockets of oil. A disc **1662** is secured to the end of the bladder **1652** at the point on the bladder which covers the oil connection. This disc **1662** prevents rupture of the bladder **1652** through the oil line **1658** when the bladder is charged with nitrogen. The disc **1662,** which is secured to the bladder **1652,** will move away from the plate **1660** when the hydraulic charge overcomes the bladder nitrogen charge, thus permitting the free flow of oil through the plate **1660** to the accumulator.

The neck **1672** of the bladder **1652** is held against the seat **1666,** and it is sealed by the bladder cover **1654.** The bladder cover **1654** is drilled and tapped to receive the previously mentioned high pressure air valve **1674.** The cover **1654** contains a small orifice **1676** which restricts the rate of flow of nitrogen from the air valve chamber **1678** to the bladder **1652,** thus preventing high nitrogen flows from the bladder **1652** in case of rupture of the air valve **1674.**

The high pressure air valve **1674** is a double seal valve, one seal being a spring loaded stem and disc similar to a conventional tire type air valve, with the second seal a metal to metal seal which is seated manually with a wrench. The bladder cover **1654** is secured in place by the steel securing ring **1668** which screws into the boss **1664** on the shell **1650.**

As shown in FIGS. **15** and **83,** the control transfer valves **1392, 1393, 1394** and **1395,** serve as the controlling units for flow of oil to the wing actuators **1382,** 1383, 1384 and **1385,** respectively. These valves control the velocity and position of the wings **112, 113,** 114, and **115.** The valves are of a linear flow spindle type. A valve spindle **1680** in each of the valves **1392,** 1393, 1394 and **1395,** is positioned axially by the torque motor **1378, 1379, 1380** or **1381,** respectively. These motors are rigidly mounted on the valve assembly. The torque motors are controlled by the DC current from the servo amplifier in the guidance control system **214.**

The transfer valve assemblies are all alike. Therefore, only one transfer valve assembly, such as **1392** illustrated in FIG. **83,** will be described. The transfer valve **1392** comprises a body **1682** containing a sleeve **1684,** a spindle **1680,** end sealing plugs **1686** and **1687,** a spindle seal **1688,** damping chambers **1690** and **1692,** and bleeds **1742** and **1744** which must be withdrawn to bleed air, if desired. The body casting **1682** forms the outer shell for the entire valve assembly **1392.** A large hole **1696** is bored into the body casting. The sleeve **1684** and spindle **1680** are fitted in this hole **1696.** Also drilled in the body casting **1682** are four hydraulic ports: an inlet port **1698,** a drain port **1700,** and two wing actuator ports **1702** and **1704.** The hydraulic system pressure of **1750** psia is applied to the valve **1392** through the inlet (high pressure) port **1698.** One of the lines **1628, 1630,** or **1632,** leading to the missile sump **1396,** is attached to the port **1700.** The remaining two ports **1702** and **1704** are connected to opposite ends of one of the wing actuators **1382, 1383, 1384** or **1385,** through tubing and flexible connectors. Other holes drilled in the casting serve as bleeding ports and damping chamber.

The sleeve **1684** is comprised of two end sections **1706** and **1708,** and a center section **1710.** Metering ports **1712** and **1714,** and inlet ports **1716** are contained in the center section **1710.** The length of this section **1710** extends from one outside edge to the other outside edge of spindle lands **1718** and **1719.**

The metering ports **1712** and **1714** are two diametrically opposite milled slots cut into the ends of the center section **1710** of the sleeve **1684.** Four round inlet ports **1716,** spaced equally around the circumference are drilled at the midpoint of the center section **1710** and connect with the high pressure inlet port **1698** in the casting **1682.** The end sections **1706** and **1708,** as well as the center section **1710** of the sleeve **1684** are secured together and fitted into the body casting **1682.** These sections are so oriented as to allow even distribution of oil flow to all the ports.

The spindle **1680** is the only moving part in the transfer valve **1392.** The spindle **1680** is machined and ground so that the two metering lands **1718** and **1719,** and the end lands **1720** and **1721** have a very smooth finish. The spindle **1680** is hand lapped in to the sleeve **1684.** A hole (not shown) is drilled axially through the center of the spindle **1680** to receive a positioning wire **1722.** The positioning wire **1722** is silver soldered into place before the finish grind operation.

The positioning wire **1722** serves as the mechanical connecting link between the transfer valve spindle **1680** and the armature of the torque motor. It is used to transmit the movement of the armature to the spindle **1680.**

Two damping chambers **1690** and **1692,** one at each end of the valve sleeve **1684,** are formed by the valve spindle outside edges and the sealing plugs **1686** and **1687** which are fitted into the body casting **1682** at each end of the main body casting sleeve hole **1696.** The two damping chambers **1690** and **1692** are filled with hydraulic oil and vented to drain pressure through a feeding orifice **1724.** The damping chambers **1690** and **1692** are connected together by a passage **1726,** which is drilled in the main body casting **1682.** This passage **1726** contains a damping orifice **1728,** which aids in damping the valve spindle oscillations and permits equalization of the pressure on each end of the spindle **1680** when it is moved.

The sealing plugs **1686** and **1687,** used to close the damping chambers **1690** and **1692,** respectively, are screwed into the main body casting **1682** and are sealed by O rings **1730.** The sealing plug **1687,** at the end of the spindle **1680** which carries the piano wire linkage **1722,** carries a positioning wire seal **1688.** This seal **1688** includes a small washer **1732,** which has a center hole of the same diameter as the positioning wire **1722.** The washer **1732** fits into a hole **1734** in the sealing plug **1687** and is held in place by a self-aligning spacer **1736,** and a retainer **1738** secured to the plug **1687** by two machine screws **1740.** The hole **1734** in the sealing plug **1687** is of such a size that the washer **1732** can be moved to obtain minimum eccentricity and it is then locked into place.

The plug **1686,** at the opposite damping chamber **1690,** is fitted with the bleed screw **1742** at its center to bleed air from the damping chamber **1690.** A second bleed point is provided by a bleed screw **1744** at the end of passage **1726.** This bleed screw **1744** is sealed by an O ring **1746,** and it is drilled to permit removal of air from the transfer valve **1392** by merely loosening the screw **1744.**

The feeding orifice **1724** connects the damping chamber **1692,** through which the positioning wire **1722** runs, to the drain port **1700.** This orifice **1724** permits oil flow to and from the damping chamber **1692** to compensate for volumetric change between the two damping chambers **1690** and **1692** due to the positioning wire **1722.** This bleed **1724** also allows the pressure in the damping chambers **1690** and **1692** to equalize with the drain pressure.

The torque motors **1378, 1379, 1380** and **1381,** FIG. **84,** which are the actuating devices for the transfer valves **1392, 1393, 1394** and **1395,** respectively, convert an electrical signal from the guidance control system **214** into a linear motion proportional in direction and amount to the polarity and amplitude of the impressed electrical signal. This linear motion is transmitted to a transfer valve such as valve **1392,** by the wire **1722.** The torque motors used in the missile **100** are linear displacement, spring balanced devices whose output motion is directly proportional to the impressed electrical signal.

unlatching tool. The pawl **411** is tapered to a nose which seats in the latching pin notch **413.** The latch **409** is spring loaded by leaf spring **417** to bear against the guide and latching pin **397,** as best seen in FIG. **25.**

After the wing lock **140** is assembled and secured to the wing lock beam **142,** the locking pin **1808** is forced into the wing lock body **1796,** compressing the wing lock spring **1806.** This extends the guide and latching pin **397** to the position where the pawl **411** engages the notch **413** on the guide and latching pin **397.** The pawl **411** of latch **409** holds the piston **1804** against the spring tension until the latch **409** is manually retracted against its spring **417** by inserting an unlatching tool through the beam **142,** as previously mentioned. When the latch **409** is retracted, the wing lock spring **1806** will move the piston **1804** to extend the locking pin **1808** into the wing, such as **112, 113, 114,** or **115.**

To retract the locking pin **1808** upon separation of the missile **100** from the booster **500,** a solenoid valve **1820,** illustrated in FIGS. **15** and **91,** is activated by a separation circuit which applies hydraulic system pressure to the top of the wing lock piston **1804.** The hydraulic pressure acts on the piston land **1810** to overcome the tension of spring **1806** and moves piston **1804** so that the locking pin **1808** is retracted from its wing while the latch **409** engages the guide and latching pin **397.** The wing lock **140** is then held in an unlocked position by the latch **409** in case of loss of power to the solenoid valve **1820.**

The solenoid valve **1820** is a three way ball type valve operated by solenoid **1822.** This solenoid is energized at separation of the missile **100** from the booster **500** by the separation circuit and it applies hydraulic system pressure to the four wing locks **140** and a pressure switch **1824,** as indicated in FIG. **15.**

The valve body **1826** is drilled and tapped for three oil connections at bosses **1828, 1830,** and **1832.** The bottom boss **1828** is used in conjunction with the hydraulic system pressure. Boss **1830** is connected to the supply line **395** to the wing locks **140** and the pressure switch **1824,** while boss **1832** is connected to the sump return line **1850.**

A split sleeve is machined to form a valve cage **1834.** This cage **1834** is seated in the valve body **1826** and sealed with O rings **1836** and **1838.** The bottom piece **1840** of the cage **1834** contains an inlet port **1842** and a seat **1844,** while a top piece **1846** thereof contains four ports **1848** which communicate with the wing lock line **395** and the sump return line **1850.** The top piece **1846** also contains return ports **1852** and a seat **1854,** and it serves as a guide for a push pin **1856.** A valve ball **1858** is contained within the cage **1834.** The valve cage **1834** is held in place by a retainer **1860** machined from stainless steel which is screwed into the valve body **1826.** A pin **1862,** secured in the body casting **1826,** engages a notch **1866** in a flange **1868** on retainer **1860,** locking it in position. The retainer **1860** also serves as a guide for a solenoid armature **1864.**

The solenoid armature **1864** is a disc type armature, and it contains ports **1870** for oil passage through it to the sump **1396.** A spring **1872** is seated within the armature **1864** to hold the armature, push pin **1856,** and ball **1858** in a normally closed position. The spring **1872** is positioned by a chrome button **1874** secured to a diaphragm **1876.** The diaphragm **1876** is a thin disc which is seated in the valve body **1826** to form an oil tight seal between the valve and a solenoid coil **1878.**

Solenoid housing **1880** is seated on the diaphragm **1876** and it is secured by four bolts **1882** to the valve body **1826.** The solenoid coil windings **1878** and a core **1884** are contained in the solenoid housing **1880** and energized through two wire leads **1886** and **1888.**

When the solenoid **1822** is not energized, the compression of spring **1872** will hold the ball **1858** against the inlet seat **1844** and permit oil flow from the wing locks **140** and pressure switch **1824** to the sump **1396.** This is the position during the boost phase of the missile **100.** On separation of the missile **100** from the booster **500,** the solenoid coil **1878** is energized, forming a magnetic field within the core **1884** which lifts the armature **1864** against the spring **1872.** This permits the hydraulic system pressure to raise the ball **1858** and allow oil to flow to the wing locks **140** and pressure switch **1824.** This hydraulic pressure will hold the valve ball **1858** against the outlet seat **1856,** sealing the sump return ports **1852.**

Three cone type, spring loaded, check valves **1890,** 1892, and **1894,** as illustrated in FIG. **88,** are used in the hydraulic system **220.** The function of these check valves is to insure that oil flows in one direction only at three critical locations in the hydraulic system **220.** These check valves are conventional fittings.

Check valve **1890** is installed in the sump return line **1850** from the solenoid valve **1820** and it functions to prevent premature action of the wing locks due to the pressure in the sump **1396.** This valve **1890** also serves to prevent draining of oil from the wing locks **140** to the sump **1396** during periods of shut-down of the hydraulic system **220** when no pressure is on the sump **1396.**

Check valve **1892** is installed between the high pressure lines of the hydraulic system **220** and the external high pressure line **1896** to the solenoid valve **1820.** This check valve **1892** prevents the entire hydraulic system **220** from being pressurized when external power is used to operate the wing locks **140.**

Check valve **1894** is installed in the pump discharge line **1898** to prevent reverse motoring of the pump **1390** during tests when an external hydraulic power supply is used. When the hydraulic system **220** is operated with internal power and load requirements are such that pump discharge pressure is less than accumulator pressure, this check valve **1894** will prevent the accumulators **122** and **1402** from discharging through the pump **1390** to the sump **1396.**

A cone type disc **1900** of the check valves **1890,** 1892, and **1894** is drilled and tapped to receive a bleed **1902,** FIG. **88.** This bleed **1902** is included to permit air entrapped in the pump **1390** and throttle mechanism **1458** to pass to the high pressure portion of the hydraulic system **220** where it can be removed by bleeding. This bleed **1902** passes sufficient oil to the pump **1390** to cause the pump to operate at low speed when the hydraulic system **220** is operated on external hydraulic power. This low speed is not sufficient to cause damage to the pump **1390.**

Four quick disconnect, self-sealing couplings **1904,** 1906, 1908, and **1910** are used in the hydraulic system piping to provide external services, including external application of hydraulic pressure during factory and field testing; to provide hydraulic drain during factory and field testing; to operate the wing locks **140** during subsystem testing; and to charge the sump **1396.**

The typical type torque motor **1378** is comprised of an armature **1748** supported by a torsion spring **1750** between two sets of magnetic poles **1752** and **1754**. Coils **1756** and **1758** surround the armature **1748**. The two sets of magnetic poles **1752** and **1754** that the armature **1748** works against are formed by two sets of heavy, highly magnetized, flat permanent magnets. The coils **1756** and **1758** surrounding the armature **1748** are so connected that when current flows in one direction, the armature **1748** is deflected in one direction, and when current flows in the opposite direction, it is deflected in the other direction.

The magnetic circuit, coils **1756** and **1758**, as well as the torsional spring **1750** are so constructed that the motion of the driving end of the armature is directly proportional to differential current applied to the coils **1756** and **1758**. The armature is balanced by a weight **1760**, mounted on the end of then armature **1748** opposite the transfer valve connection **1722**. This balance reduces motion of the end of the armature due to a high frequency vibration.

The operational sequence of the torque motor **1378** and transfer valve **1392** will now be discussed. A DC differential current from the guidance control system **214** is applied to the torque motor coils **1756** and **1758**, causing the torque motor armature **1748** to move. This motion, transmitted to the transfer valve spindle **1680** by the connecting wire **1722**, causes the spindle **1680** to move. When the spindle **1680** moves, land **1719** uncovers one set of metering ports **1714** to the drain port **1700**, while the other land **1718** uncovers the other set of ports **1712** to the high pressure oil contained between the spindle lands **1718** and **1719** from the inlet port **1698**.

Thus, oil flows from the valve inlet port **1698**, across the valve spindle **1680** between the lands **1718** and **1719** to the metering ports **1712** connected to high pressure, through the metering ports **1716** and thence to outlet port **1702** to one side of a wing actuator, such as actuator **1382**. As the actuator **1382** moves, oil from its opposite side is forced to the transfer valve **1392**, through the other set of metering ports **1714** to the valve drain port **1700** and the missile sump **1396**.

The wing actuators **1382**, **1383**, **1384**, and **1385** are hydraulic-mechanical devices which serve to move the wings **112**, **113**, **114**, and **115**, respectively, and hold them in any position from 20° clockwise to 20° counterclockwise from the longitudinal axis of the missile **100**. Hydraulic flow of the oil to and from the actuators **1382** through **1385** is controlled by the transfer valves **1392** through **1395**, respectively.

As illustrated in FIGS. **20**, **21**, and **85**, an actuator assembly, such as actuator **1382**, is composed of a body **1764**, a cylinder cover **1766**, a sealing nut **1768**, a piston assembly **1770**, and sealing O rings **1772** and **1774**. The piston **1770** of the actuator **1382** has two grooves **1776** machined on its periphery for piston rings **1778**.

A mechanical stop **1780** is machined in the closed end of the body casting **1764** for the piston **1770**. A piston rod hole **1782** is machined in the center of the cylinder cover **1766**. This hole **1782** is grooved to permit the O ring **1774** to be fitted between the piston rod **1386** and the cylinder cover **1766** to seal against oil leakage past the piston rod. Oil leakage between the cylinder cover **1766** and the body casting **1764** is also sealed against by the O ring **1772**. The cylinder cover **1766** acts as one of the mechanical stops for the piston **1770**.

A cylinder nut **1768** holds the cylinder cover **1766** and the body **1764** together. The cylinder nut **1768** fits over the cylinder cover **1766** and locks the cover to the main body **1764**. The nut **1768** also permits the cover **1766** to be moved radially to insure that the piston rod **1386** is aligned.

The piston rod **1386** is threaded at the end and it has a keyway (not shown) cut in it for a castellated nut that prevents rotation of the piston **1770**. The threaded end of the piston rod **1386** is screwed into a threaded eye **1784** and locked in place by means of a nut **1786** and a lock washer **1788**.

The piston rod **1386** is adjusted to give equal throw to the wings **112**, **113**, **114**, and **115** by screwing it in or out of the threaded eye **1784**, and locking it in place by the lock nut **1786** and lock washer **1788**. Two bosses **1790** and **1792**, one on the body casting **1764** and one on the hydraulic cover casting **1766**, are threaded to receive tubing **1794** from the control transfer valves **1392** through **1395**.

In operation, hydraulic oil is applied to one side of piston **1770** causing it to move, thereby moving the wing **112**, **113**, **114**, or **115**, through the bell crank **329**, and displacing the oil on the opposite side of the piston **1770**.

In order to maintain the aerodynamic alignment of the missile **100** during the boost phase when the servo system is inactivated and sufficient hydraulic pressure is not available in the wing actuators **1382** through **1385** to hold the wings **112**, **113**, **114**, and **115** at the zero position, it is necessary to pin the wings in their zero position. This is done by the previously mentioned four hydraulically operated wing locks **140**, one for each wing mounted on the wing lock struts **142**.

As illustrated in FIGS. **25**, **86**, and **87**, each wing lock body **1796** contains an internal cylinder **1798**, which is externally threaded to receive an end cover **1800**, a boss **1802** threaded for a hydraulic oil line **395**, and brackets **416** for the piston latch **409**. A piston **1804** and a piston spring **1806** fits into the wing lock body **1796**. The wing lock piston **1804** is formed integrally with a locking pin **1808**, a land **1810**, and the previously mentioned guide and latching pin or rod **397**.

One end **399** of the locking pin **1808** is machined with a tapered flat **1812** on each side to form a wedge which engages a recess **401** in the wing rib **311**, as previously discussed. The land **1810** is spaced from the other end of the piston **1804**. An O ring **1814** is seated in a groove **1816** adjacent this land **1810** to form a seal between the land and the wall of the cylinder **1798**. The latching pin **397** of the piston **1804** has the previously mentioned notch **413** provided therein and a keyway **1818**. The keyway **1818** cooperates with a pin (not shown) which is seated in the cover **1800**, to prevent the piston **1804** from turning.

The wing lock spring **1806** is fitted over the guide and latching pin **397** and is seated within the piston land **1810** where it is held in position by the wing lock end cover **1800**. The cover **1800** is internally threaded to mate with the threads on the body **1796**. The piston guide and latching pin **397** passes through a hole **1820** provided in the cover **1800**. The piston latch **409** is fabricated from steel plate. This latch is claw shaped, with a lever arm and the previously mentioned pawl **411**. The latch **409** is provided with notch **407** to receive an

The four quick disconnect couplings **1904** through **1910** are standard commercial items. Therefore, a detail description of the couplings is not provided.

Two large filters **1404** and **1406,** as illustrated in FIG. **89** each incorporate a cartridge **1912** and, are used in the hydraulic system **220** to assure a dirt-free hydraulic oil supply to the transfer valves **1392** through **1395** and the wing actuators **1382** through **1385.**

One filter **1404** is used to filter all oil flow to the transfer valves **1392** and **1393** which control wings **112** and **113,** respectively. The other filter **1406** is used to filter all flow to the wing locks **140** and to the transfer valves **1394** and **1395** which control wings **114** and **115,** respectively. The body **1914** of the filters **1404** and **1406** contains a spring loaded relief by-pass valve **1916,** located between an inlet port **1918** and an outlet port **1920.**

In addition to the two large filters **1404** and **1406,** two smaller filters **1922** and **1924,** FIG. **90,** are used in the external lines **1896** and **1410** to the hydraulic system **220.** One filter **1924** is used in the sump charge line **1410** and the other filter **1922** in the wing lock external supply line **1896.** A relief valve disc **1926,** loaded by spring **1930** supports filter element **1928.**

The operation of the hydraulic system **220** in connection with aerial flight of the missile **100** will now be described. As soon as the missile-booster combination begins to accelerate, the air scoop **772** provides air through channel **1280** in the intake strut **774** for the hydraulic pump **1281** so that the turbine **1418** will begin rotation. The throttle control piston **1604,** since no hydraulic pressure exists, will be in full throttle position. Consequently, the turbine **1418** will accelerate rapidly. Since the pump **1390** and turbine **1418** are connected directly through a gear reduction assembly **1400,** the pump **1390** will immmediately begin pumping oil.

When the pressure of the hydraulic system **220** has reached 1,000 psia, any further pump stroking will not be acting against a non-yielding system, since the oil pressure is now greater than the accumulator precharged nitrogen pressure. Consequently, the accumulators **122** and **1402** will consume oil, and as a result of increased oil storage, the nitrogen will be compressed. The accumulator pressure will, therefore, rise as the nitrogen volume decreases. The net yield will be system pressure rapidly rising to nominal value, while the pump **1390** is storing oil in the accumulators **122** and **1402** at the same pressure.

The oil volume stored in the accumulators **122** and **1402** must, of course, come from the pressurized sump **1396.** During the system pressurizing period, the sump **1396** will have discharged oil, and, consequently, the sump pressure will decrease. The sump **1396** will contain enough oil to keep the intake pressure to the pump **1390** above 20 psia and thus will prevent cavitation.

When the pressure of the hydraulic system **220** has reached a level of 1,750 psi, the throttle control piston **1604** will close, thus decelerating the turbine **1418.** If all action described above takes place before the boost phase of the missile **100** is completed, the speed of the turbine **1418** may actually decrease quite rapidly. If, however, the boost phase of the missile **100** is completed, the hydraulic system **220** will demand some oil flow which will not allow the turbine **1418** to slow down as rapidly, or if demand is great enough, may even call for more speed from the pump **1390.** However, on the basis of flight data and calculations, the hydraulic pressure should actually be 1,750 psi some time before the boost phase of the missile **100** is completed.

At the time of separation of the missile **100** from the booster **500,** tail end separation switches will close, thus energizing the solenoid valve **1820** in the wing lock sub-system **1398.** The valve **1820** will supply system pressure to the wing locks **140** and the wing locks will retract, leaving the wings **112, 113, 114,** and **115** free to rotate.

The missile guidance system **214** will also energize at separation of the missile **100** from the booster **500.** Undoubtedly response to a relatively large roll error will be required at separation of the missile **100** from the booster **500** due to missile roll misalignment encountered during boost. The pressure of the hydraulic system **220** will decrease because of this demand, and, as a consequence, the pump throttle control piston **1604** will again permit more air to flow to the turbine **1418.** The turbine **1418** will accelerate to keep up with the demand, and, in the interim, the accumulators **122** and **1402** will supply oil to the system. In the event of a decrease in flow demand, the turbine **1418** will decelerate to the speed corresponding to the new flow requirements and, during this deceleration period, the accumulators **122** and **1402** will store the excess oil.

Assuming initial capture of the missile **100,** the midcourse guidance phase will probably be the quietest period of operation for the hydraulic system **220** during flight of the missile. The operation of the hydraulic system **220** will probably be a somewhat milder form of the capture phase characteristics. All flow to the wing actuators **1382, 1383, 1384,** and **1385** will pass through the filter-transfer valves circuit and then into the sump **1396** for re-cycling through the pump **1390.** Some cooling will take place in the sump **1396,** although this will be a direct function of quantity of oil in the sump **1396** and thus of the pressure of the hydraulic system **220.**

The terminal guidance phase of the missile **100** will probably be the most severe case for the hydraulic system **220.** This is a result of the following conditions:

1. Noise level in the homing guidance sub-system is expected to be high, and consequently, jitter in the wings **112, 113, 114,** and **115,** will probably result. This will call for large demands of oil flow from the valves **1392** through **1395;**
2. Air pressure will be at its lowest value, and, consquently, available power from the pump **1390** will be at its lowest value. Response time of the system will undoubtedly be greater; and
3. Oil temperature will be at its highest value.

The missile constituting the subject matter of the instant invention may incorporate any one of the several well-known guidance and/or homing systems.

The booster **500,** illustrated in FIGS. **44** through **61,** utilized for propelling the missile **100** to a nominal separation velocity of approximately 2000 ft/sec is comprised of a large, solid propellant rocket which provides approximately 370,000 lb/sec of impulse for a period of approximately 4 seconds. This booster **500** supports the missile **100** before launching from a zero length trainable launcher **1000,** FIG. **61** (or a dual launcher for shipboard use). The weight of the booster **500** less its two pairs of fins **257** and **259,** and **256** and **258,** is estimated at approximately **2,850** pounds. The pairs of fins **257** and **259,** and **256** and **258** are attached to the booster **500** for longitudinal stability of the missile-booster combination.

The case **501** for the booster **500** is a cylinder. At one end **3999** of this cylindrical case **501**, there is attached a convergent-divergent nozzle **4000** by means of threaded bolts 4002, FIG. **60.** The end **3999** of case **501** supports aft launching and handling shoes **4005** and **4007**, respectively. A gasket **4004** is positioned between a flange **4006** of the nozzle **4000** and the inner surface of the thickened end **3999** of the booster case **501** to prevent gas leaks.

The nozzle **4000** is manufactured in two sections **4038** and **4040** which are welded together at **4042** just aft of the throat **4044** of the nozzle, as best seen in FIG. **60.** Heat resistant inserts (not shown) can be provided in the nozzle **4000**, or other means can be provided for cooling the nozzle **4000.**

The exterior of the nozzle **4000** is encased in a shroud **4046** to reduce air drag. This shroud **4046** is attached to a rearwardly extending annular flange portion **4047** of the nozzle **4000** by means of bolts **4049**, with an annular ring **4051** being secured between the shroud **4046** and the flange portion **4047** of the nozzle **4000** to reinforce the structure.

A nozzle closure disc **4003** is inserted in the nozzle exit **4052** to seal the nozzle **4000** in order to prevent loss of propellant solvents and to prevent entrance of moisture into the propellant grain **4184.** It is manufactured of a light metal sheet and is generally inserted in the exit **4052** of the nozzle **4000**, although it can be made smaller and inserted near the throat **4044** of the nozzle. When the propellant grain **4184** of the booster **500** is ignited, this disc **4003** is blown out of the exit **4052** of the nozzle **4000** after aiding in the initial build up of the pressure in the booster.

Two pairs of U-shaped annular channels **4060**, mounted back-to-back (web-to-web), in spaced relationship, are utilized for securing the fin spars **4062** and **4064** from each fin **256, 257, 258** and **259** to the booster **500.** Annular doublers **4066** and **4068**, together with a cylindrical member **4070**, are utilized to reinforce the channels **4060.** The fin spars **4062** and **4064** are secured between the spaced pairs of channels **4060** by means of bolts **4072.** A flange portion **4074** of each channel **4060** is secured to the shroud **4046** by welding or the like. The shroud **4046** is reinforced in the vicinity of each fin spar **4062** or **4064** by straps **4078** and **4080**, respectively, which gird the shroud. Stringers **4083** are located between the inner channels **4060** to reinforce the shroud **4046**, while an annular channel **4082** is utilized to reinforce the downstream end of the shtoud **4046.**

At the other end **4010** of the booster case **501**, a forward head **4012** (closure) is bolted thereto by means of bolts **4014**, as best seen in FIGS. **46** and **47.** A gasket **4016** is utilized to seal the shoulder portion **4018** of the forward head **4012** to the forward end **4010** of the booster case **501.** This forward head **4012** supports an igniter **4020**, an igniter arming device or mechanism **4022**, a grain immobilizer **4024**, a resonance rod assembly **4026**, a plurality of clamping ring guards **4028**, forward pairs of launching and handling shoes **4030** and **4032**, respectively, as well as the booster thrust ring **4034** (formed integral with the forward head **4012**) and clamping ring **4036**, FIGS. **46** and **47.**

As shown in FIGS. **44, 46,** and **47,** the missile **100** and the booster **500** are held together by means of the clamping ring **4036** whose flange portions **4091** and **4093** mate with machined surfaces **4092** and **4094** on the missile aft ring **4096** and booster thrust ring **4034**, respectively. The missile aft ring **4096** is secured to the cylindrical section **284** of the missile by means of rivets **4097.**

The clamping ring **4036** is so designed that, when it is unlocked by a striker arm **4098** on the launcher **1000**, it springs outwardly into the six ring guards **4028** on the booster **500**, thus unlocking the booster and missile **100.** During the boost phase of aerial flight of the missile **100**, the missile-booster combination is held together only by the thrust of the booster **500.** The thrust is transmitted from the booster **500** to the missile **100** by mating machined surfaces **4099** and **4101** on the missile aft ring **4096** and the thrust ring **4034**, respectively, as best seen in FIG. **47.**

As illustrated in FIG. **46**, the clamping ring **4036** is constructed of two semi-circular sections **4103** and **4105.** One end of each section **4103** and **4105** of the clamping ring **4036** is secured to a bracket element **4107** or **4109**, respectively, by means of bolts **4111.** These bracket elements **4107** and **4109**, in turn, cooperate with an adjustment screw **4113** to provide a turnbuckle **4114.** Bifurcated bracket elements **4112** and **4115** are secured to the opposite ends of sections **4103** and **4105**, respectively, of the clamping ring **4036** by bolts **4108**, as shown in FIG. **46, 48,** and **49.**

A scissors hinge **4117**, having its two arms **4119** and **4121** pivotally connected together by a pin **4123**, is pivotally mounted to the bifurcated bracket elements **4112** and **4115** by pins **4110** and **4118**, respectively. This scissors hinge **4117** permits concentric opening of the clamping ring **4036** so that the latter will unlock the missile aft ring **4096** and booster thrust ring **4034.**

A bifurcated yoke **4116**, as shown in FIGS. **48, 49,** and **50,** keeps the arms **4119** and **4121** of the scissors hinge **4117** together so that the sections **4103** and **4105** of the clamping ring **4036** are held in operative position. A shear pin **4131** is utilized to hold the yoke **4116** and arms **4119** and **4121** of the hinge **4117** together so as to prevent premature release of the sections **4103** and **4105** of the clamping ring **4036.** When the striker arm **4098** releases the yoke **4116** by shearing the pin **4131**, the two arms **4119** and **4121** of the scissors hinge **4117**, are forced apart by leaf springs **4125**, FIGS. **56**, 57 and **58.** These springs **4125** are mounted on the inner surface of the clamping ring **4036** and they force the clamping ring sections **4103** and **4105** outwardly to release the clamping ring as indicated above.

A bracket **4601**, FIGS. **49** and **50**, is secured to the booster casing **501** by suitable means, such as screws **4603** or the like. Two vertically extending and spaced eyelugs **4602** are provided as an integral part of bracket **4601** for receiving a bolt **4606.** Yoke **4116** likewise has two spaced lugs **4608** formed integral therewith. Each lug **4608** has a hook portion **4612** formed at the end thereof, as seen best in FIG. **49.** The hook portion **4612** of each lug **4608** engages with the bolt **4606.** Each lug **4608** has a semi-circular recess **4614** provided in its surface for receiving a pin **4616.**

The lower end **4617** of a lever **4618** is pivotally secured to the bolt **4606** which extends through the eyelugs **4602.** Lever **4618** is provided with a longitudinally extending recess **4620** for receiving a spring **4621.** An elongated slot **4622** is also provided in lever **4618** through which the pin **4616** is inserted so that it can be supported by the lugs **4608**. The spring **4621** is inserted in the recess **4620** through an aperture **4625** in end **4624** of the lever **4618**. The aperture **4625** is closed by a screw **4626**. The lower end of the spring **4621** is positioned on the pin **4616** by a pin **4630** which is secured to pin **4616** at a right angle thereto. The upper end of the spring **4621** rests against the screw **4626** in aperture **4625**. Spring **4621** biases the lever **4618** to the position shown in FIGS. **48**, **49** and **50**. A mousetrap spring **4632**, secured to the bolt **4606**, is utilized to bias the lever **4618** in the stowed position, as indicated by the phantom lines in FIG. **49**.

When the booster **500** is ignited and moves forward, the striker **4098** hits the upper end **4634** of the lever **4618**, causing it to rotate about the bolt **4606**. When this occurs, the yoke **4116** is pulled rearwardly by pin **4616** to shear the pin **4131** and release the sections **4103** and **4105** of the clamping ring **4036**, as previously described.

As best seen in FIGS. **56**, **57**, and **58**, there are six leaf springs **4125** provided approximately equidistantly spaced around the inner periphery of the clamping ring **4036**. These springs **4125** insure that the clamping ring **4036** expands concentrically with respect to the missile aft ring **4096** and the thrust ring **4034** upon release of the sections **4103** and **4105** of the clamping ring **4036**. These leaf springs **4125** are secured to the clamping ring **4036** by rivets **4128**.

Six ring guards **4028**, as shown in FIGS. **46**, **47**, **56**, and **57**, spaced equally around and attached to the forward end of the case **501** of the booster **500** by forwardly extending bracket members **4132** are employed to retain the clamping ring **4036** to the booster **500** after separation of the missile **100** therefrom. Members **4132** are secured to the booster case by bolts **4014**. A ring guard **4028** is secured to each member **4132** by rivets **4136** as shown in FIG. **56**.

As seen in FIGS. **46**, **53**, **54**, and **55**, two separation signal arms **4140** and **4142** are located 180° apart on the horizontal centerline of booster flight. Each arm **4140** or **4142** is secured to a U-shaped bracket **4143** by a bolt **4144**. Each bracket **4143**, in turn, is attached to the booster case **501** by a bolt **4014**. Each arm **4140** or **4142** protrudes from the forward end of the booster case **501** and mates with the missile **100** as will now be described.

Each signal arm **4140** and **4142** has a tongue portion **4146**, which is received between the missile skin **286** and a spaced member **4148**, which is secured to the missile skin by machine screws **4150**. When the signal arms **4140** and **4142** are in position, the tongue portions **4146** thereof prevent the missile ignition system from being activated by preventing the biased elements **4152** in the microswitches **4154** from moving upwardly through apertures **4155** and **4156** in the missile skin **286** and member **4148**, respectively, to complete electric connections. The signal arms **4140** and **4142** thus activate the missile ignition system as the booster **500** separates from the missile **100**, as will be described. The microswitches **4154** are supported on the missile skin **286** by members **4160** and bolts **4162**, and are contained in housing members **4164**, with the latter being attached to the section **284** by welding or the like.

Referring now to FIGS. **46**, **51**, and **52**, two indexing lugs **4170** and **4172** are used to position the booster **500** to the missile **100**. These lugs **4170** and **4172** are located on the horizontal centerline of launch (viewed looking aft the booster **500**) of the missile-to-booster thrust ring **4034** as best seen in FIG. **46**. Two rectangular shaped notches **4174** (only one of which is shown in FIGS. **51** and **52**) are provided in the missile aft ring **4096** for receiving the lugs **4170** and **4172**. These lugs **4170** and **4172** are mounted in notches **4176** formed in the surface of the missile-to-booster thrust ring **4034**. The lugs **4170** and **4172** are secured in the notches **4176** of the thrust ring **4034** by rivets **4178**.

The two sets of forward and aft launching and handling shoes **4030** and **4032**, and **4005** and **4007**, as best seen in FIGS. **44**, **45**, **46**, **47**, **61**, **62**, and **64**, are attached to the booster casing **501**. The forward launching and handling shoes **4030** and **4032**, respectively, are secured to the casing **501** with bolts **4180**. The aft launching and handling shoes **4005** and **4007** are secured to the rear end **3999** of the casing **501** by bolts **4182** adjacent the forward end of the booster nozzle **4000** as best seen in FIGS. **59** and **62**. The forward and aft launching shoes **4030** and **4005**, respectively, ride in track assemblies **4412** and **4414** of the launcher **1000**. These track assemblies **4412** and **4414**, as will be described in more detail subsequently, support the missile-booster combination for the first **9** inches of its travel.

The propellant for the booster **500** is contained in a cylindrical grain **4184** pierced longitudinally by a plurality of spaced slots **4186**, FIGS. **47**, **59** and **60**. A cast double base propellant is used in the booster **500**. The casting powder is a modified nitrocellulose powder. The solvent used contains approximately **75** percent nitroglycerin, **24** percent plasticizer, and **1** percent stabilizer. The propellant is cast into a cellulose acetate cylinder (restrictor) which acts to prevent burning on the outer surfaces of the propellant grain **4184**. Burning of the propellant is confined to the end of the grain **4184**, and the surfaces of the longitudinal slots **4186** in the grain.

The propellant casting powder is comprised of nitrocellulose grains containing about **9** percent of a heavy metal compound, usually a lead compound. Lead stearate can be used. The addition of a heavy metallic compound modifies the burning of the propellant such that, in a given burning rate regime, the burning rate is relatively independent of ambient temperature. Burning of this type is termed "platonic" burning due to the "plateau" formed in the burning rate curve. The presence of the plateau is extremely desirable, as rocket thrust variation with propellant temperature is held to a minimum over the plateau range.

Whenever hot gases are forced to flow in a narrow channel at high velocity over a burning propellant surface, as they are in the booster **500**, a phenomena termed "resonant burning" takes place. This type of burning results in extreme pressure fluctuations which may be severe enough to shatter the grain **4184** and rupture the case **501**. In order to eliminate this phenomena, the resonance rod assembly **4026**, FIGS. **47** and **59**, is used. This assembly **4026** consists of resonance rods **4188** which are merely small diameter steel rods supported at the forward end by straps **4190** and **4191**, and placed in the slots **4186** through which the gases flow. These rods **4188** effectively eliminate the resonance burning and result in a smooth burning pressure and smooth thrust output.

To prevent the booster case **501** from becoming overheated and weakened, the after end of the propellant grain **4184** is sealed to the booster case by resting against the shoulder **4006** machined on the booster nozzle **4000**. A seam sealing compound or gasket **4004** is used between the shoulder **4006** and the case **501** to provide a gas tight seal. The grain **4184** is held down against the shoulder **4006** by springs **4192** of the grain immobilizer **4024**. These springs **4192** are located between buttons **4193** located adjacent the inner surface of the forward head closure **4012** and pads **4194** placed adjacent to the upstream surface of the grain **4184**. Telescoping rod members **4195** and **4196** are secured to the buttons **4193** and pads **4194**, and the springs **4192** are placed about the rod members **4195** and **4196**, as shown in FIG. **47**, and the entire assembly is kept in operative position by straps **4197** positioned about annular rings **4341** and **4343**. The springs **4192** provide a sealing force of between **775** and **925** pounds on the grain **4184** at −10° F. These springs **4192** also prevent shifting of the grain **4184** during handling and transportation of the booster **500**, and eliminate the need for seating the grain by elevating the launcher **1000** to maximum elevation before firing.

A typical curve of booster chamber pressure versus time is shown in FIG. **98**. It will be noted that chamber pressure varies but little with changes in grain temperature. In FIG. **99**, there is illustrated a typical curve of thrust in pounds versus time for the booster **500**. The characteristics of the booster **500** for various temperatures are tabulated below:

	40° F.	77° F.	125° F.
Total Impulse	371,000 lb/sec	372,000 lb/sec	374,000 lb/sec
Burning Time (defined)	4.10 sec	4.0 sec	3.70 sec
Average Thrust	91,600 lbs	95,000 lbs	106,000 lbs
Maximum Thrust	95,600 lbs	99,000 lbs	111,000 lbs
Time at Maximum Thrust	0.2 sec	0.33 sec	0.25 sec
Maximum Pressure	1085 lb/sq in	1125 lb/sq in	1290 lb/sq in
Average Pressure	1030 lb/sq in	1080 lb/sq in	1220 lb/sq in

The igniter **4020** for the booster **500** is mounted on the forward head **4012**, as seen in FIGS. **46** and **47**. The electrical circuit for the igniter **4020** is illustrated in FIG. **100** (shown on the same sheet of drawings with FIGS. **56**, **57**, and **58**). The igniter **4020** consists of a metal base **4302**, which is a removable part of the forward head **4012**, with an attached plastic cup **4304** attached thereto by means of an annular ring **4305**. The ring **4305** has an inwardly extending flange **4307** provided integral therewith for mating with an outwardly extending flange **4309** on the cup. The annular ring **4305** is internally threaded and it is screwed on an externally threaded flange **4311** formed integral with the base **4302**.

Cup **4304** contains an igniter charge **4306** and four electrical squibs **4308** connected together by leads **4310**, **4312**, **4313**, **4314** and **4315**, with leads **4312** and **4313** being connected to the metal base **4302**, as shown in FIGS. **47** and **100**. The center of lead **4310** is also connected to the terminal **4303** on the base **4302**. A cone **4375** is utilized on base **4302** to insulate terminal **4303**. A pin **4319** is utilized to pin the base **4302** to an annular flange **4321** formed integral with the forward head **4012**.

A metal ring **4316** is provided for locking the igniter **4020** to the forward head **4012**. This ring **4316** is scalloped in twelve equally spaced sections **4301** on its inner surface to provide therebetween circumferential sections **4317**, and these sections **4317** fit over a corresponding number of circumferential lips **4318** formed on a flange **4323** which is formed integral with the igniter base **4302** to retain the igniter **4020** in the forward head **4012** when the booster **500** is armed. A retaining ring **4325**, having a shoulder **4327** to cooperate with a flange **4329** on the ring **4316** maintains the metal locking ring **4316** in operative position.

In the safe position, the igniter lock ring **4316** is located so that the scalloped sections **4301** of ring **4316** are in alignment with the lips **4318** on the base **4302**. A thin shear ring **4331** is positioned between the base scalloped sections **4317** and the lips **4318** to hold the base **4302** in position. If accidental ignition of the igniter **4020** should occur, the ring **4331** is sheared and the igniter base **4302** is ejected from its position in the forward head **4012**, thus rendering the booster **500** non-propulsive. When the igniter **4020** is armed, the igniter lock ring **4316** is positioned so that the sections **4317** are located in alignment with the lips **4318** so as to retain the pressure load, thus maintaining the booster **500** in a propulsive state.

The igniter charge **4306** is comprised of a mixture of **300** grams of cannon black powder, **700** grams of black powder, and **500** grams of 0.012 inch thick trench mortar sheet powder which is cut into small segments. The four electrical squibs **4308** are wired in a series-parallel circuit and are, as previously indicated, internally grounded by leads **4312** and **4314** to the igniter base **4302**. A lead **4362** is used as a jumper between the base **4302** and the booster forward head **4012**.

The igniter **4020** is so mounted that, when it is in the safe position, the leads **4330** and **4332** for the squibs **4308** are disconnected from the firing lead **4540** and are shorted together to ground through the pole arm **4377** of a single pole double throw microswitch **4338**.

To arm the booster **500**, an arming handle (not shown) is inserted in the igniter arming device **4022** and rotated 90°. As illustrated in FIGS. **46** and **47**, this arming device **4022** has a gear sector **4344** mounted on its end which meshes with a second gear sector **4346** attached to the lock ring **4316** by screws **4350**. This rotates the igniter **4020** 22 ½°, removes the short to ground on the squib leads **4330** and **4332** and connects the igniter **4020** to the firing circuit.

A fixed mechanical contact element **4352**, as shown in FIG. **46**, which is secured to the lock ring **4316** by a bracket **4356** and screws **4358**, makes contact with a plunger **4360** on the switch **4338** to move pole arm **4377** to complete connection with contact **4379** and, at the same time, completes the firing circuit to lead **4540**. The locking ring **4316**, at the same time, locks the igniter **4020** in the forward head **4012**. Switch **4338** is secured to the forward head **4012** by a bracket **4366** and screws **4368**.

The launcher **1000**, FIG. **61** comprises a central tubular column **4400** which is adapted to be fastened to the ground or a deck surface of a ship. A forward supporting leg **4402**, and two aft supporting legs **4404** are provided which hold the column **4400** in a vertical position and also assist in restraining the column from lateral motion. A boom **4408**, which is adjustable in elevation, is pivotally mounted on the upper end of the central column **4400**. A hydraulic actuator **4406** is provided for elevating the boom **4408**. Leveling means are provided on the legs **4402** and **4404** and are used to adjust the legs with respect to the central column **4400**, thereby prestressing the launcher **1000** to withstand launching forces.

Mating forward and aft track assemblies **4412** and **4414** are carried by the boom **4408** and are arranged to cooperate with the forward and aft launching shoes **4030** and **4005**, respectively, on the booster **500**, as best seen in FIGS. **61** and **64**, so that the missile **100** can easily be mounted on the boom. The mounting arrangement is such that the missile **100** is immediately freed of the launcher **1000** upon firing of the booster **500**.

The launcher **1000** includes the central column **4400** which is supported by a base **4416** at its lower end. This base **4416** includes a plate **4418** which has an aperture (not shown) provided therein. This aperture is aligned with a second aperture in a block of concrete or similar material to which the base **4416** is attached by suitable means so that electrical cables, such as cable lead **4592**, can be introduced into the interior of the column **4400** and boom **4408**. A ball and socket arrangement (not shown) is mounted between the lower end of the column **4400** and the base **4416**, respectively, to provide a pivotal connection between the base and column.

The cental column **4400** is held in vertical alignment and restrained from lateral motion by the arrangement of three supporting legs generally resembling that of a tripod and include the relatively long forwardly extending leg **4402** and two relatively short rearwardly extending legs **4404** (only one of which can be seen in FIG. **61**). Because of the position of the missile **100** on the launcher **1000**, the elements of the forward leg **4402** are made larger and structurally stronger than those of the rearwardly extending legs **4404**. Each leg **4402** and **4404** is in the form of a simple truss. Legs **4404** each comprise spaced tubular members **4420** and **4422** interconnected by an end sleeve **4424**, cross-member **4426** and gusset **4428**. Leg **4402** comprises spaced tubular members **4430** and **4432** interconnected by a sleeve **4434**, a cross-member **4436**, and a gusset plate **4438**, with all of these elements being structurally stronger than the corresponding members of legs **4404**.

The tubular members **4430** and **4432**, and **4420** and **4422**, of the respective legs **4402** and **4404**, are provided with flanges **4440** at their inner ends, which are removably attached by bolts **4442** to corresponding flanges **4444** carried on short tubular sections **4446**, welded to column **4400**, the weld joints being reinforced by gussets **4448**.

The sleeves **4434** and **4424** at the outer ends of the legs **4402** and **4404** carry adjustable feet **4450**. Each assembly includes a plate **4452** having a sleeve **4454** mounted thereon, the sleeve being reinforced by gusset plates **4456**. A ball seat member (not shown) is mounted at the bottom of the sleeve **4454** for supporting a ball (not shown), which is fastened on the lower end of a post **4458** by a pin (not shown) and is retained in the sleeve **4454** by a retainer ring (not shown) screwed into the upper end of the sleeve **4454**. This construction provides a ball and socket connection between each foot and post **4450** and **4458**, respectively, at the outer ends of each of the legs **4402** and **4404**.

The post **4458** has a threaded intermediate portion (not shown) which is screwed into a threaded aperture in a bushing (not shown), with the bushing being carried in the lower end of the supporting sleeve **4434** or **4424**. A ring (not shown) is welded on the inside surface of the supporting sleeve **4434** or **4424** adjacent the upper end thereof to provide a shoulder, and an apertured guide disk, in which the upper portion of the post **4458** is journaled, is retained against the shoulder by an elongated cylindrical spacer extending between the bushing and disk. The upper end **4460** of the post **4458** is square to receive a wrench for adjusting the foot **4450** in the supporting sleeve **4434** or **4424**.

Referring again to FIG. **61**, the tapered boom **4408**, which is of substantially rectangular cross section, is mounted on the upper end of the column **4400** by a pivotal connection generally indicated by reference numeral **4462**. A plate **4464** having an aperture therein (not shown but used for the electrical cable **4592** brought up through the interior of the column **4400**) is carried on the upper end of the column **4400**, and it is attached to the column by a plurality of gusset plates **4466** which are welded to the column **4400** and plate **4464**. The pivotal connection **4462** comprises a pair of spaced trunnion mounts **4468** attached to a plate **4470**. This plate **4470**, in turn, is secured by bolts **4472** to the underside of the boom **4408**, nearer the larger end thereof. A pair of laterally spaced yokes or pillow blocks **4478** are bolted to the upper surface of the plate **4464**. Pins **4480** are inserted in aligned apertures provided in the trunnion mounts **4468** and pillow block **4478** to complete the pivotal connection **4462**.

The boom **4408** is comprised of an inner section **4482** and an outer section **4484** having flanges **4486** and **4488**, respectively, which can be joined by pins, bolts or any desired means. The boom **4408** is fabricated from plate stock and it is hollow and substantially rectangular in cross section. Access apertures **4490** and aperture **4492** are provided in the boom **4408**, the former adjacent the inner end of the boom and the latter adjacent the outer end thereof.

Forward and aft track assemblies **4412** and **4414**, which cooperate with the forward and aft booster shoes **4030** and **4005**, respectively, as best seen in FIGS. **61**, **62** and **64**, are supported on section **4484** of boom **4408**, as will now be described. The track assemblies **4412** and **4414** are removably mounted on a plate **4496** which is attached by bolts **4498** to the underside **4494** of boom section **4484**, with suitable spacers **4499** being inserted between the plate **4496** and the boom underside **4494**.

The plates **4496**, FIGS. **62** and **63**, are provided with a notch **4502** along their longitudinally extending edges which notches are adapted to receive eye-bolts **4504**. These eyebolts **4504** are pivotally mounted on bolts **4506** journaled in spaced yokes or lugs **4508** projecting from opposite sides of a box structure **4510**. This box structure **4510** consists of a channel **4511**, which has a plate **4513** welded to the top thereof, as best seen in FIG. **64**. The aft end is similarly provided with spaced yokes or lugs **4508** for bolts **4506** which pivotally mount eye-bolts **4504**. The foward track assembly **4412** includes two forward tracks **4520** which are welded to the box structure **4510**, with each track being provided with a groove **4516** into which a lip **4518** in the corresponding forward booster shoe **4030** projects.

The aft track assembly **4414** is generally similar to the forward track assembly **4412** except for the details of the aft track **4514.** In the aft track assembly **4414,** the single launching shoe **4005** is T-shaped in cross-section and is received, as shown in FIGS. **62** and **64,** in a correspondingly shaped recess **4526** in the aft track **4514.** This aft track **4514** is welded to the underside of channel **4511.** Tapered pins, such as pin **4530,** shown in FIG. **62,** are utilized to position the box like structure **4510** with respect to plate **4496.** Stop **4532,** as shown in FIG. **63,** is provided in the recess **4526** near its aft end to prevent rearward movment of the booster **500** when it is mounted on the launcher **1000.**

In FIGS. **46, 64** and **65,** the details of the electrical connections to the igniter lead **4540** are illustrated. As shown in FIG. **65,** a flat groove **4542** is provided in the upper surface of left hand forward launching shoe **4030.** A strip **4544** of insulating material is placed in the groove **4542,** and a strap **4546** of conducting material is positioned on top of the strip **4544.**

The ends of the strap **4546,** as shown in FIGS. **46, 62** and **64** are shaped to fit over the front and rear surfaces of shoe **4030** and are attached thereto by screws **4543,** only one of which is shown. As indicated, the strip **4544** of insulating material is similar in shape to strap **4546,** and it separates the strap **4546** from the shoe **4030.** A shouldered bushing (not shown) of insulating material is provided between the strap **4546** and the screws **4543.** A terminal lug **4545,** insulated from the shoe **4030** and screw **4543** by the shouldered bushing, is held in electrical contact with strap **4546.** This terminal lug **4545** is carried on one end of the igniter lead **4540** from the igniter **4020.**

As shown in FIGS. **64** and **65,** an insulating block **4548** of phenolic material is secured to the side **4550** of the box structure **4510** by suitable means, such as screws **4552,** which pass through apertures **4549** in the block **4548** and which are received in threaded apertures **4554.** Block **4548** is provided with a vertically extending aperture **4556** which is of reduced diameter for the lower half of the block **4548** and of enlarged diameter for the upper half thereof.

A metal rod **4558** is inserted in the aperture **4556** in the block **4548,** and then a coil spring **4560** is inserted about the upper end thereof in the enlarged diameter portion of the aperture. An insulating sleeve **4562** is then inserted about the upper end of the rod **4558,** and it is pinned to the rod **4558** by a pin **4564.** Coil spring **4560** thus biases the rod **4558** upwardly by pushing against the sleeve **4562** and the shoulder **4569** in the aperture **4556.** This rod **4558** provides an electrical contact **4566** on its upper end. An enlongated slot **4568** is provided in the rod **4558** near its lower end, and a pin **4570** is inserted through an aperture **4571** in the block **4548** and through slot **4568.** The pin **4570** allows limited vertical movement of the rod **4558** and retains the rod **4558** in the block **4548** when the launcher is unoccupied.

Electrical connection between the rod **4558** and the metal strap **4546** is provided by a strap **4574** which has one end **4576** thereof inserted into an aperture provided in the lower end of the rod **4558,** and whose other end **4578** has a contact element **4580** mounted thereon. This element **4580** rests on the metal strap **4546.**

Plate **4496** is provided with an aperture **4581** into which there is inserted a sleeve **4582** formed of insulating material. A metal rod **4584** is inserted in the sleeve **4582,** and it is provided with an enlarged end contact **4586** for mating with contact **4566** on the upper end of rod **4558.** The upper end of rod **4584** is threaded to receive two nuts **4588.** A terminal lug **4590** from cable lead **4592** is positioned between these two nuts **4588.** Cable lead **4592** is passed through an aperture **4594** in the side wall **4596** of boom **4408.** This cable lead **4592** is passed through the boom **4408** and column **4400.** It will be discussed more subsequently in connection with the igniter firing circuit for the booster **500.**

Terminal lug **4590,** cable lead **4592,** and nuts **4588** are contained in a housing **4591,** which is secured to the side wall **4596** of the boom **4408** by bolts **4593.**

Referring to FIGS. **63** and **64,** the forward track assembly **4412** is provided with a removable safety stop **4640** to prevent displacement of the missile **100** from the boom **4408.** The removable safety stop **4640** is formed of heavy rod and is received in a suitable aperture **4641** provided in the forward track **4520** and it can be readily withdrawn from the path of the booster shoe **4030** by means of a circular handle **4642.**

The release lever striker **4098** is mounted on the right side of the launcher boom **4408,** looking in the direction of the missile **100.** An outwardly extending channel **4644** is secured to the box structure **4510,** as best seen in FIGS. **63** and **64,** by suitable means such as bolts **4651.** A second channel **4646** is, in turn, secured to the outwardly extending channel **4644.**

This second channel **4646** is located substantially parallel to the box structure **4510** but is spaced therefrom. A gusset plate **4648** is used is strengthen the channels **4644** and **4646.** A pair of spaced lugs **4650** are welded to the forward end **4654** of channel **4646.** The release lever striker **4098,** in the form of a bolt, is supported by these lugs **4650,** and it is positioned so as to strike the upper end **4634** of lever **4618** when the booster **500** is ignited and moves forward, as previously described, thereby releasing the sections **4103** and **4105** of the clamping ring **4036.**

As best seen in FIG. **61,** the hydraulic actuator **4406** is used to elevate the launcher boom **4408** to the desired firing angle. The actuator **4406** is of a conventional type and it includes a cylinder **4660** which is pivotally mounted on the column **4400** near its lower end. This pivotal mounting includes a plate **4662** attached to the column **4400** and having apertured lugs **4664** integral therewith. A hinge **4666** is carried on the lower end of the cylinder **4660** and a pin **4668** is inserted through aligned apertures provided in the lugs **4664** and the hinge **4666.** The piston rod **4670** of the hydraulic actuator **4406** is pivotally attached at its upper end to the inner end of the boom **4408.** A pair of spaced stop rods (not shown) located on either side of, and parallel to the piston rod **4670,** are likewise pivotally attached at their upper ends to the boom.

The pivotal connection between the piston rod **4670** (as well as the stop rods) and the boom **4408** includes a plate **4674** attached by bolts **4676** to the end of boom section **4482.** The plate **4674** has three pairs of suitably spaced apertured lugs **4678** formed integral therewith. The upper ends of the piston rod **4670,** as well as the two stop rods, are provided with sleeve bearings **4680,** and a shaft **4682** is inserted through aligned apertures in the bearings and the lugs, with the shaft being retained in position by snap rings (not shown) provided adjacent its outer ends.

The stop rods (not shown) are slidably carried in spaced apertures provided in a stop block **4648** on cylinder **4660.** A fully comprehensive description of the elevating mechanism and attendant details is provided in the patent application of Arthur H. Miller, Jr., Ser. No. 437,016 for a LAUNCHER, filed June 15, 1954.

The operating mechanism for the hydraulic actuator **4406** includes a pump driven by an electric motor, a valve, and a tank for the hydraulic fluid, and is mounted in a housing **4686** on the lower member **4432** of the forward leg **4402.** A control handle (not shown) is provided on the housing **4686.** Since these elements are conventional, no detailed description is given herein.

A pair of hydraulic leads (not shown) interconnect the pump housing **4686** and the hydraulic cylinder **4660,** with one lead being connected to the lower end of the cylinder and the second lead being connected to the upper end thereof. Flexible sections (not shown) are provided in the hydraulic leads to permit bending as the cylinder **4660** moves about its lower end. A flow limiter is inserted in the upper hydraulic lead to limit the flow out of the cylinder **4660** in the event a power failure stops the pump. The flow limiter prevents a loaded boom **4408** from moving rapidly to its lowermost position.

An indicator (not shown) is mounted on the column **4400** for assisting in vertically aligning the column.

As shown in FIG. **61,** a panel **4690** is also provided on the central column **4400** for mounting such controls as may be needed, and an oil filler tank **4692** is provided on the column **4400** for filling the actuator cylinder **4660.**

It is belived that the general mode of operation of the launcher **1000** will be apparent from the foregoing detailed description. To facilitate mounting the missile **100** and its booster **500** on the boom **4408,** the forward and aft track assemblies **4412** and **4414** and box structure **4510** are removed and are mounted on the booster **500,** the forward booster shoes **4030** being received in the grooves **4516** of the forward track assembly **4412** and the aft booster shoe **4005** being received in the T-shaped recess **4526** in the aft track assembly **4414.** The missile **100** and the booster **500** are then raised to a position near the boom **4408** and in alignment therewith, so that the eye-bolts **4504** can be swung into their respective notches **4502.**

With the missile **100** in position, the central column **4400** can be aligned vertically by adjusting the feet **4450,** if necessary, and prestressing of the launching structure can also be accomplished, if desired, by adjusting the feet **4450** with the central column **4400** fixed. The stop rings are then adjusted along the stop rods to positions corresponding to the desired angle of elevation of the boom **4408,** and the hydraulic actuator **4406** is energized to raise or lower the boom **4408** to the required angle. Firing is accomplished by the ignition of the booster **500** from a remote point, as will be described subsequently, through the medium of an electric current applied through the leads **4592** and **4540.** Because the forward and aft tracks are extremely short, the missile **100** and booster **500** are quickly freed from the launcher **1000.**

The missile of the present invention may utilize a conventional warhead, or a warhead of the type described in U.S. Patent application, Ser. No. 590,077, filed June 7, 1956, E. L. Nooker and M. L Kempton, Inventors (application assigned to U.S. Government). Such a warhead is shown in FIGS. **66–68** of the drawings.

The fuze **182** for the missile **100** is a fixed angle, narrow beam, microwave, influence type proximity fuze, having a range of approximately **140** feet. As shown in FIGS. **1, 4,** and **43**A, the fuze **182** is located in the forward annular nose section **104** of the missile **100** below the fuze compartment cover **190.** Six fuze antennae **184** are located in section **104** to provide the radiation pattern at a fixed angle with the longitudinal axis of the missile.

The fuze **182** is designed so that its radiation pattern coincides with the dynamic burst pattern of the warhead **194.** The fuze **182** transmits microwave energy, which, when the missile **100** is sufficiently close to the target **2000,** is reflected and received by the fuze to produce a voltage which actuates the detonators **4800,** which, in turn, detonate the warhead **194.**

In order to insure operation of the fuze **182** on the correct target **2000** and to insure maximum damage from the blast pattern of the warhead **194,** steering intelligence information is fed to the fuze, thus enabling it to trigger at the optimum time in flight for any approach to the target **2000.**

The safety and arming device **132,** as illustrated in FIGS. **1** and **101,** renders the warhead **194** and/or self-destruct charges inoperative until such time as it is deemed safe to detonate these charges. The arming of the self-destruction charge will not be covered since the operation is identical to arming of the warhead **194.** The safety and arming device **132** will not allow the warhead **194** to arm until an electric circuit is provided for the detonate signal from the fuze **182,** and a flame path is provided between the detonators **4800** and the booster for the warhead **194.**

The operation of the safety and arming device **132,** in order of events, will now be explained in conjunction with FIG. **101.** Two selector switches **4900** and **4902** on the safety and arming device **132** are adjusted and locked before launching of the missile **100.** Switch **4900** is utilized to select either the warhead **194** or exercise head **196**; while the other switch **4902** is used to select the arming time, either **9** or **18** seconds after launching of the missile **100.**

The next event in the operation of the safety and arming device **132** is to provide an intent to launch signal to the safety and arming device. This signal is received when internal power is applied to the missile **100** approximately **45** seconds prior to launching of the missile **100.** This applies −330 volts through a resistor **4904** to contact **4906** on the safety and arming device connector **4904,** and also provides −330 volts on the contacts **4910** and **4912** of a G operated switch **4914.**

At zero time, the missile **100** is launched. When the missile **100** attains a **10**g acceleration, the switch **4914** moves to position **4916.** This applies −330 volts to a resistor **4918** through the contacts **4910** and **4920,** thus providing a charge path for a capacitor **4922.** When the voltage on capacitor **4922** rises to a high enough potential, gas discharge tubes **4924** and **4926** fire, thus causing a current flow through the squibs **4928** and **4930** on the explosive dimple motor **4932.** The RC time constant of resistor **4918** and the capacitor **4922** is selected so that it will require **2.25** seconds for the gas discharge tubes **4924** and **4926** to fire. The −330 volts is also applied to a capacitor **4934** charging it very quickly to −330 volts. It should be noted that unless the **10**g acceleration of the missile **100** is sustained for 2.25 seconds, the capacitor **4922** will not charge to a potential sufficient to fire the tubes **4924** and **4926.**

When the current flows through the squibs **4928** and **4930** on the explosive dimple motor **4932,** the squibs **4928** and **4930** fire and the motor drives the switch **4914** to position **4936** and locks it in this position. When the switch **4914** locks in position **4936,** it provides a discharge path for the capacitor **4934,** through contacts **4938** and **4940** on switch **4914** through resistors **4942, 4944,** and a capacitor **4946.** Consequently, capacitor **4946** starts charging. When the potential across capacitor **4946** rises high enough, gas discharge tubes **4948** and **4950** fire and cause current to flow through squibs **4952** and **4954** on an explosive bellows motor **4956.**

The RC time constant of capacitor **4934,** resistors **4942** and **4944,** and capacitor **4946,** is selected so that the time for the gas discharge tubes **4948** and **4950** to fire will be **15.75** or 6.75 seconds after the G switch **4914** has been in position **4936.** As stated previously, this time was determined by the setting of selector switch **4902** before launching of the missile **100.**

The motor **4956** is mechanically connected to a plate **4958,** and switches **4960, 4962,** and **4964.** When the squibs **4952** and **4954** of motor **4956** fire, the motor drives the plate **4958** to the position that connects the detonators **4800** electrically to ground at point **4966** and to the detonate signal lead at point **4968.**

Also, the detonate signal path is completed from the fuze **182** by the rotation of the switch **4962** and plate **4958,** when rotated, completes the flame path from the detonators **4800** to the booster of the warhead **194.** This completes warhead arming. It should be noted that switch **4900** determines whether the detonate signal will be sent to the warhead **194** or to the exercise head **196.**

An exercise head assembly **196** is used in lieu of the warhead **194,** as shown in FIG. 43C, to obtain flight data for research and development. This also permits operation against an actual target **2000,** such as an aircraft, without destroying it.

The exercise head assembly is composed of two sections **4840** and **4842.** Section **4840** contains the telemetering equipment **206,** while the other section **4842** contains various telemetering components, several (two) spotting charges, and a self-destruct charge.

The two spotting charges, which are used to simulate warhead detonation, are exploded by igniters. Actuation of the igniters is controlled by the fuze **182.** Each spotting charge produces a smoke puff with an intensity of 8 megalumens. The self-destruct charge is fired upon command from the steering intelligence system **212.** Both the spotting charges and the self-destruct charge are armed by the safety and arming device **132.**

The missile weapon system is comprised of the equipment necessary to effectively deliver fire upon high speed hostile aircarft with the missile **100,** as previously described, at ranges up to 100,000 yards and at altitudes up to 60,000 feet. The missile weapon system includes search and height finding radars, identification equipment, target designation systems, the missile fire control system, the handling and launching equipment, the missile **100** with its various systems as previously described, and the personnel and supply systems necessary to insure proper utilization of the missile **100.**

The missile weapon system can be used on land or aboard a missile ship, and when used aboard the latter, it functions to provide long range, high fire-power antiaircraft defense to a task group, supplementing conventional weapons. The missile ship, of the light cruiser type, mounts two dual launchers **5400,** only one of which is shown in FIG. **103.** One of the launchers **5400** is located in the forward part of the ship while the other is mounted in the aft portion thereof and on the main deck. A typical missile ship will carry missiles, stowed in magazines **5401,** as shown in FIGS. **104** and **105.**

The missiles **100** are received aboard the missile ship, the hydraulic system **220** pressurized, and fuel tanks **138** filled. Missiles **100** and boosters **500** are shipped in airtight cans. Immediately on arrival aboard the ship, the missiles are decanned, mated, and taken below deck where they are horizontally stowed. Wings **112,** 113, 114, and **115,** and fins **116, 117, 118,** and **119** are not attached until just prior to firing of the missile-booster combination.

In the vertical stowage and loading plans, mated, fueled and charged missile-booster combinations, with the warhead **194** and fuze **182** installed, are placed on stowage arms in racks capable of holding a plurality of missile-booster combinations each. At least four racks are required to serve one dual launcher **5400.** The launcher **5400** is located between them, and above the tops of the stowage arms. Four blast doors are located in the deck immediately beneath the launcher **5400.** These doors allow passage of the missile-booster combination and the rammer loader. It can be readily seen that the compartmentation and watertight integrity problems in this type of installation become immense. It requires a space beneath each dual launcher **5400** of approximately 28 feet wide, 34 feet long, and 35 feet high. This height will extend from the first platform deck up to the first (**01**) deck and second (**02**) deck, respectively.

Mounted on a cylindrical platform are nine stowage arms. These arms are supported at the top and bottom, and are arranged to travel independently around the cylindrical platform. In this position, only one set of fins and wings for each missile **100** can be installed permanently. Space will not permit the installation of the other pair of fins and wings on the missile, until the missile-booster combination reaches the final position before being rammed up to the launcher **5400.** Also, a rather large strike down area is required.

Warmup power can be applied to all of the missile-booster combinations on the stowage arms. A Go-No-Go tester is used to check out the missile **1100.** However, here if a missile-booster combination fails this test, it can be easily cycled around to the rear of the cylinder and a new missile-booster combination brought up for test.

In horizontal stowage and loading, on the other hand, mated, fueled and charged missile-booster combinations are stored below the ship deck in horizontal racks. Each of the stowage racks is a watertight compartment. The missile-booster combination is placed on a light dolly which, in turn, is mounted on rails. The rails run athwartships and terminate at the hoist. The hoist is provided with short rails on it which will mate with the rails from the racks. The missile-booster combination will be rolled out to the hoist and onto the hoist to the standby position.

When a missile-booster combination is needed in the wing and fin assembly room, the hoist is run up to this room and the missile-booster combination is transferred to the ram assembly. Here the wings and fins are installed after the final Go-No-Go test has passed. In the floor of this room, there will be located inside blast proof doors. It is through these doors that the missile **100** will be passed from the hoist to the ram assembly. At the front of this room, and directly behind the launcher **5400** it will serve, another pair of blast proof doors is provided. These two pairs of doors are so interconnected by interlocks that only one set can be open at any one time. This is to prevent any accident in one room being spread into any other room.

A retractable rail, operating on an overhead pivot, is located directly behind the blast proof doors. This rail is swung out when the outside blast proof doors are open to make the rail connection from the wing and fin assembly room to the launcher **5400.** When this rail is in position, the rammer assembly is cycled to move the missile-booster combination onto the launcher arm. Because of the close tolerances in the shoes that hold the missile-booster combination to the launcher arm and the ram assembly, the launcher **5400** is locked in the loading position and not simply held there by action of the elevate and train servos.

After the missile-booster combination has been transferred from the dolly on the hoist to the ram assembly, the dolly can be returned to the strike down area to await the arrival on board of the resupply missile-booster combination.

If the warhead **194** has not been previously installed during shipment, a separate warhead hoist is utilized to bring the warheads **194** up from their magazine to the wing and fin assembly area for installation in the missile-booster combination. The warhead **194** is in two halves, each semi-circular in shape as previously described, and these halves are bolted around the missile **100** prior to firing. The fuzes are installed at this same time.

The fuel and hydraulic systems **230** and **220**, respectively, are designed to be tight in order that they can be charged at the time the missile-booster combination is originally mated, and they will remain in this condition at all times during storage. The missile batteries are also charged and installed at this same time.

The main advantage of this type of horizontal storage and handling system is that the ship as a whole can be made much more watertight, and the system of compartmentation can be better carried out in the missile handling compartments of the ship. The actual cubic space requirements are approximately the same for both the horizontal and vertical systems for storage of the missile-booster combinations. However, some extra equipment will be required, such as the dollies and the hoist.

The launchers **5400** are of the dual type, capable of firing salvo fire, with the two missiles **100** being separated in space by about **2** seconds. These launchers **5400** are located in the normal main battery positions, that is, two forward and two aft, on the ship centerline. The No. 1 and 4 launchers will be on the main deck, while the No. 2 and 3 will be on the first **(01)** deck of the ship.

The launchers **5400** are trainable through 360° and can be elevated up to 90°. Cut-out circuits will be employed to prevent the firing of missiles **100** into the superstructure of the firing ship.

To load a missile-booster combination onto the arms of the launcher **5400,** it is only necessary to train the launcher **5400** around to either 0° or 180° relative, and either elevate or depress to 90° or 0°, open the blast doors, and then operate the rammer. In the vertical load system, the launcher **5400** must be at 90° of elevation to load it, while in the horizontal load system it must be 0°.

In the vertical load system, any launcher **5400** can be loaded when at either 0° or 180° relative, while in the horizontal load system previously described, the two forward launchers **5400** must be at 0°, and the aft launchers **5400** must be at 180° relative. This may tend to slow down the rate of fire for the horizontal load system.

In both stowage systems, the missile-booster combination is carried on a loading arm, which is attached to the rammer. This loading arm is identical to the launcher arm, and when it is in physical contact with the end of the launching arm, the rammer pushes the missile-booster combination off of the loading arm onto the launching arm. A one way catch snaps shut after the missile **100** passes over it on the launcher arm. This will prevent the missile-booster combination from falling off of the launcher **5400** during the retraction of the rammer and during the elevation and training of the launcher.

As shown in FIG. **102**, the ship will have two independent installations for firing missile salvos. Each installation **5402** and **5404,** called a defense unit, consists basically of one launcher **5400**, one launcher computer **5406**, two tracking and illuminating radars **5408** and **5410**, two predictors **5411** and **5413**, two beam programmers **5415** and **5417**, two guidance transmitters **5412** and **5414**, a control console **5434**, and a data receiver and transmitter **5432.**

A missile direction center **5418** is utilized to coordinate the actions of the defense units **5402** and **5404.** This direction center **5418** keeps track of all targets **2000**, and designates them to the two defense units **5402** and **5404.**

If it is assumed that a target **2000** has been detected by a combat information center **5420**, it is evaluated and assigned to the missile direction center **5418** as a target. The target **2000** is designated to a defense unit, say defense unit **5402**, which issues a warmup order to the launching system and commences tracking the target **2000.**

The launching system automatically performs the sequence of operations described below. It starts the warmup of the missile **100**; and it transfers missiles **100** from the magazine **5401** to loader area **5422** where wings **112, 113, 114,** and **115,** and fins **116, 117, 118,** and **119,** are attached to missile **100**, and the fins **256,** 257, 258, and **259** are attached to the booster **500.** In addition, it rams the missile salvo onto the launcher **5400**; and then it elevates and trains the launcher **5400** to the proper position as determined by the launching computer **5406.**

The launching computer **5406** also determines the initial train and elevation of the assigned guidance transmitter **5412** or **5414** for missile capture, correcting for the effects of gravity drop, parallax, and wind.

As soon as the guidance transmitter **5412** or **5414** is synchronized to the proper position, the firing sequence is initiated. At the instant the firing command is given, launcher orders are frozen to the true space values then existing, and held until the second missile **100** of the salvo is fired. The beam position of the guidance transmitter **5412** is also held fixed in true space for the first **6** seconds after firing to facilitate beam capture by both missiles **100.** As soon as the second missile **100** is clear of the launcher **5400,** the launcher slews to the reload position.

How the missile weapon system fits into the overall air defense scheme will now be explained. All raids approaching a task group will be evaluated on the task group command level and certain targets will be assigned to the ship. Aboard the ship these target assignments are received in the missile direction center **5418,** which, in turn, designates the targets **2000** to the two defense units **5402** or **5404.** Each defense unit **5402** or **5404,** operating in the dual-simplex mode of operation, is capable of simultaneously controlling two missile salvos. The function of each part of the weapon system, illustrated in FIG. **102,** is illustrated below.

The combat information center **5420** detects and identifies all targets **2000**; and it continuously tracks all targets **2000.** In addition, this center **5420** correlates all available data about each target **2000** which will assist the evaluation and weapon assignment operations. It also evaluates the relative threat of the various targets **2000**; selects the targets **2000**; and there it distributes the targets **2000** among the missile ships.

The missile direction center **5418** designates assigned targets **2000** to the two defense units **5402** and **5404.** Targets **2000** are assigned successively in priority sequence until each defense unit **5402** or **5404** is loaded to capacity. Subsequent targets **2000** are assigned in priority sequence as the tracking channels are released from their prior targets. In designating targets to a defense unit **5402** or **5404,** consideration is given to the tracking radar and guidance transmitter blind zones.

The missile defense unit **5402** or **5404** is the combination of equipment required for firing the missile **100.** Each defense unit **5402** or **5404** operates on its assigned targets **2000** independently of the other defense unit, and it is capable of autonomous operation in the event of battle damage. The defense unit controller directs and coordinates the operation of the guidance transmitter **5412** or **5414,** tracking radars **5408** and **5410,** and the launching system.

In response to the orders received from the missile direction center **5418,** the controller signals the launching system as to the missile **100** which is to be fired. The controller then selects the tracking radar **5408** or **5410** and guidance transmitter **5412** or **5414** which is to be used against a particular target **2000** after considering blind zone regions with respect to the present and predicted intercept positions of each target.

Firing is normally automatic after receipt of the designation data from the missile direction center **5418** as soon as all the conditions required for successful intercept are satisfied. Among these are targets **2000** within range; missiles **100** warmed up on the launchers **5400**; the launcher **5400** pointed correctly; and the guidance transmitter **5412** or **5414** positioned for capture. The defense unit commander will have the firing circuit under his control so that he can prevent automatic firing if such is called for by his overall knowledge of defense unit status and safety conditions. In addition he will be able to bypass interlocks for emergency firing.

Each defense unit **5402** or **5404** contains two tracking and illuminating radars **5408** and **5410** which provide target position and rate data to the predictors **5411** and **5413** and beam programmers **5415** and **5417,** and provide target illumination for the homing guidance sub-system of the missile **100.** The radars **5408** and **5410** consist basically of two separate radar systems, one for acquisition and one for tracking. Both of these operate simultaneously and transmit through the same antenna lens.

The acquisition system supplies a narrow beam that scans a volume in space approximately 5° wide, 5° high, and 10,000 yards deep in range. The acquisition bean assists in the process of locking the track beam on a designated target. The track system, which is of the simultaneous lobing type, supplies a narrow 1.6° beam for automatic tracking. Using both systems, it is possible to survey the space surrounding a target **2000** while the target is being tracked.

The two predictors **5411** or **5413** control the automatic sequence of defense unit operations. Each predictor **5411** or **5413** is permanently associated with a particular channel of the target tracking system. Each predictor **5411** or **5413** continuously computes the three coordinates of the predicted target intercept point; the missile time of flight to predicted intercept point; and the time duration required for the beam program.

The operations listed below are automatically initiated by the predictor **5411** or **5413** on the basis of these computations. The loading of the launcher **5400** is initiated about **50** seconds before predicted firing; and then the firing of the missile **100** is initiated. The tracking radar **5408** or **5410** is then directed to acquire its next target **2000** when the predicted intercept time for the present target is reached. The guidance transmitter **5412** or **5414** is released for use with the next salvo fired.

The launching computer **5406** performs three functions in controlling the relationship between the target **2000,** launcher **5400,** guidance beam and missiles **100.** The launching computer **5406,** using predictor data, generates the train and elevation orders for setting the launcher **5400** to its firing position. For all targets **2000** having a predicted intercept point beyond **50,000** yards, the launching elevation angle with respect to the horizon will be approximately 40°. For closer intercept ranges, the required setting varies in 5° steps between 25° and 50°. At the instant the firing command is given, the launching computer **5406** freezes the launcher position to the true space values then existing and holds it fixed in this position until the second missile **100** of the salvo is fired.

The launching computer **5406** also determines the initial train and elevation angle of the guidance transmitter beam. Since the missile **100** is not guided during the boost phase, but is only attitude stabilized, it is necessary that the guidance transmitter beam be positioned properly to capture the missile **100** when its guidance control system **214** is activated. The initial train and elevation positions required of the guidance transmitter beam are obtained by adding the effects of gravity drop, parallax and wind to the angles of the launcher **5400.** The guidance transmitter beam position is held fixed in true space for the first **6** seconds after firing, and the beam position programming is initiated at this time.

The launching computer **5406** also will measure the cross traverse displacement of the launcher **5400** at the instant the missile gyroscopes are uncaged and will generate orders for corresponding displacements of the polarization and modulation axes of the guidance transmitter assigned to that salvo. These guidance transmitter axes will be continuously modified during missile flight to compensate for changes in cross traverse position resulting from both beam programming and ship motion.

The beam programmer **5415** or **5417** programs the position of the guidance radar beam so that the missile **100** follows an up-and-over trajectory. The program used for the elevation position of the guidance transmitter beam is:

$$E_G = E_t + \left(\frac{E_o - E_t}{4}\right) 1 + \cos \pi \left(\frac{T_{gp}}{1.2\ T_{gi}}\right)^2 \qquad \text{, Eq. (17) .}$$

where

E_G is the present elevation angle of guidance transmitter **5412** or **5414**;

E_t is the present elevation angle of target **2000** (from tracking radar **5408** or **5410**);

E_o is the elevation angle of the guidance transmitter **5412** or **5414** at the instant of firing the missile salvo;

T_{gp} is the time from start of beam program to present time (F (t) potentiometer); and

T_{gi} is the time from start of program to predicted intercept time (from predictor **5411** or **5413**).

It can be seen that when $T_{gp} = 0$, $E_G = E_o$; and when $T_{gp} = 1.2\ T_{gi}$, $E_g = E_t$, showing that the guidance beam is programmed into coincidence with the tracking radar beam at the end of the program. A similar program is used in the azimuth.

Each defense unit **5402** or **5404** includes the previously mentioned guidance transmitters **5412** and **5414** for the concurrent control of two missile salvos. These units produce the beams along which the missiles ride. The beam is conically scanned.

The launching system operates under the overall control of the predictors **5411** or **5413** of the defense unit controller. Thus, missile type selection, initiation of launcher loading, and initiation of firing are all under the direction of the defense unit controller.

Except for the launcher **5400**, the entire launching system is enclosed in an armored deckhouse. As previously mentioned, automatically operating doors separate the launcher **5400** from the loader area and another set of doors separates that area from the magazine. It takes approximately **50** seconds for a missile salvo to be hoisted to the loader area, have aerodynamic surfaces installed, be rammed onto the launcher **5400**, and be elevated to firing position. Immediately after firing, the launcher **5400** returns to the horizontal reload position.

The general operation of the overall missile system will now be described. In response to signals generated in the radar **3408** (or **5410**) and launcher controller **5434** in the missile direction center **5418**, the launcher **5400** (with two missile-booster combinations on the launcher arms) trains and elevates to the firing bearing and quadrant elevation. The bearing is very nearly that of the target **2000**, while the elevation varies with the range, being high for long range and low for short range.

The same computer **5406** through the beam controller **5415** trains the midcourse guidance transmitter **5412** so that its axis is in coincidence with the predicted missile position at the end of boost. This midcourse guidance transmitter **5412** does not track the missile **100**, but it transmits pulses of RF energy in the beam **2024**. This beam **2024** is programmed in elevation to give the Up and Over trajectory that is desired for long range and fuel economy, coincident with target tracking.

When the firing circuit is closed through the pair of microswitches **4154**, shown in FIG. **53**, a programmed series of events takes place. The missile **100** is switched to internal power, a backscratcher (not shown) (a missile launcher electrical receptacle is shown on line **1**, FIG. **43D** through which the external power is applied) for furnishing external power is lifted and the booster **500** is fired. This booster **500** will deliver 370,000 lb/sec of impulse, which is equivalent to about 93,000 pounds of thrust for about 4 seconds. This thrust is sufficient to bring the missile **100** to near its designed velocity, 2000 ft/sec, at an altitude of between two or three thousand feet, depending upon the firing quadrant elevation.

When the thrust from the booster **500** has been expended, its greater aerodynamic drag causes it to slow down faster than does the missile **100** and it falls away from the missile. This action completes the separation circuits in the missile **100.** This activates the fuel control system **230** and the beam riding guidance subsystem **2012.**

During the boost phase of aerial flight of the missile-booster combination, excessive dispersion of the point of separation caused by wind, and aerodynamic or jet misalignments can be expected. At the present time, this dispersion is reduced by the use of the large booster fins **256, 257, 258,** and **259.**

At separation of the missile **100** and booster **500**, the flares in the combustor **108** are ignited and the ramjet engine takes over the propulsion of the missile. This engine burns the fuel in the annular can combustor **108** to give thrust and keep the missile **100** at its designed velocity. As previously mentioned, two burner sections are present in the combustor namely, a main burner and a pilot burner. The purpose of the pilot burner is to stabilize the burning in the main combustor **376** and to ignite the main burner if the main fuel flow shuts off due to missile velocities exceeding the design velocity. The main fuel regulator **380** regulates fuel flow to the combustor **376** to hold the missile velocity at 2000 ft/sec.

The tank **442** of nitrogen aboard the missile, operating through a pressure regulator unit **444**, pressurizes the neoprene bladders **438** inside the fuel tank **138** to a pressure equal to ram air pressure plus **28** pounds per square inch. The nitrogen system provides a positive head of fuel to the pump **440** to overcome acceleration forces at launch, prevent cavitation and fuel boiling at high altitudes.

Ram air picked up by the scoop **772** inside the air duct **266** goes through the air turbine **770** which turns the fuel pump **440.** This assures a constant flow of fuel to the fuel regulator valves which control its flow to the pilot and main combustors.

The hydraulic system **220** is also pressurized by means of pump **1390** which is operated by the air turbine **1282.** This turbine **1282** also runs off of ram air, in a similar manner to the fuel pump **440.** The hydraulic oil flows from the previously pressurized accumulators **122** and **1402,** to the actuator valves that move the wings **112, 113, 114,** and **115,** then back to a sump tank **1396** where it waits to be recirculated by the pump **1390.**

It is assumed that at the end of the boost phase of aerial flight, the missile **100** will be in such a position in the beam **2024** of the guidance transmitter **5412** that the beam rider receiver **2042** can determine the location of the missile in this beam and commence to steer the missile along it. However, if for some reason the orientation of the missile **100** were such that the missile were upside down and high in the beam, the receiver **2042** would determine that the missile was high in the beam and send a down-signal to the wings **112, 113, 114,** and **115.** But since it is upside down, a down-signal would make the missile **100** go up and cause it to get farther out of the beam **2024.** For this reason, the output of the beam rider receiver **2042** is shorted to ground for **1.1** seconds. This is sufficient time for the roll control system to bring the missile into its proper orientation in space (flight attitude).

The roll control system operates constantly during the midcourse phase of the flight to keep the missile in the proper orientation. Roll position is obtained from the roll free gyroscope **2790** and roll rate is obtained from a roll rate gyroscope **2063.** The outputs of these two gyroscopes **2790** and **2063** are mixed to give the desired amount of damping and prevent oscillations about the proper roll position.

During the time that the output signal of beam rider receiver **2042** is not utilized, the roll system can send signals to the wings **112, 113, 114,** and **115** for roll stabilization as high as 150° per second. After this time the tail end signals are limited to 80° per second, insuring at least 70° per second for roll signals. There are no separate roll control flippers but the wings **112, 113, 114,** and **115** are operated differentially to cause the missile **100** to roll. Thus, no extra hydraulic system is needed for the roll system.

The guidance radar **2023** puts out its energy in the form of pulses. Each transmission will consist of the required pulses separated in time variable amounts, up to a total time for the known number of pulses of known microseconds. These will form a code group that the missile **100** can be made to receive. Any other code grouping will be rejected.

The pulse coding is necessary to prevent missiles **100** fired into different guidance beams **2024** from being confused, and for antijamming purposes.

The beam rider receiver **2042** picks up the transmissions of the guidance radar **2023** through the single teflon lens antenna **2002** that is pointed aft and is located on the missile body aft between wings **113** and **114.** As the guidance transmitter **2022** (or **5412** or **5414**) nutates at **30** revolutions per second, the repetition rate of the emission of the pulses is changed ±5 percent around the basic rate of 900 pulses per second.

The incoming pulses are fed to the superhetrodyne receiver **2042,** the local oscillator **2048,** of which is controlled by an automatic frequency controller referenced to the incoming TE frequency. The signal voltage produced by the receiver **2042** has a 30 cycle component, the amplitude of which is proportional to the missile error angle and its phase is proportional to the missile position in the beam. This is fed in quadrature into a pair of phase comparators **2034** and **2036.** The reference voltage is obtained from the **30** cycle frequency modulation of the radar pulse repetition rate. The outputs of the phase comparators **2034** and **2036** are proportional to the error angles in each of the planes.

The missile **100** never knowns exactly how far from the center **2032** of the beam (axis of nutation of the radar) it is, since the amplitude modulation of the 30 cycle voltage is proportional to missile angular error. That is the angle, measured at the radar **2023,** between the axis of nutation **2032** and the missile **100.** In the computer, a motor driven linear potentiometer picks off more and more of the error signal as a function of time, thus converting the angular error to one of distance, since time can represent range in this constant velocity missile **100.** However, this occurs only during the first **13** seconds after separation; after this time it is assumed that any error will be small and it can be used directly without conversion.

During this time, the guidance control system **214** is acting upon the signals received from both the roll stabilization system **2040** and the beam rider receiver **2042** and using them to position the wings **112, 113, 114,** and **115.** The servos in the guidance control system **214** have feedback loops to tell them just what the wings **112, 113, 114,** and **115** are doing in response to the signals sent to them. In addition to these feedback loops, there is the overall aerodynamic feedback loop that measures the missile motion and feeds this back into the system to cancel commands present and executed.

The homing guidance sub-system **2014,** as previously mentioned, is a semiactive radar interferometer device which produces steering signals by measuring the angular rate of change of the missile **100** to target line of sight **2052.** This measurement is done in each of the planes of the wings **112, 113, 114,** and **115** and so two complete systems are present, one supplying commands to the odd wings and the other the even wings. The switch over from beam riding to homing is automatically accomplished when the homing guidance sub-system **2014** receives sufficient energy from the target **2000.**

The tracking radar **2028,** under orders from the computer, tracks the target **2000** only during the time that the missile **100** is in its homing phase. This radar energy is reflected from the target **2000** into the four teflon homing antennae **20004, 2005, 2006,** and **2007,** in the nose of the missile **100.** The signal from one antenna, say **2006,** in channel "A", passes through a continuous microwave phase shifter **2218,** and is then added to the signal from the other antenna **2004.**

This produces a pulsed signal which is amplitude modulated at the frequency of the phase shifter **2218** and by the relative angular velocity of the target **2000** with respect to the missile **100** to target line of sight **2052.** Thus, any deviation in the frequency of the amplitude modulation of the incoming signals from that produced by the phase shifter **2218** is due to either the motion of the target **2000** or missile **100.** There are two homing rate gyroscopes **2060** and **2061** to measure missile motion and this is subtracted from the signal to give only target motion.

The automatic range tracking unit **2020** receives a signal from the beam rider receiver **2042** to start its time sweep. It produces a one-fourth microsecond gate signal which is applied to the gate video amplifier of each homing channel. Before homing guidance commences this gate sweeps in range from about 7000 feet in front of the missile **100** to about 26,000 feet.

If a signal (echo from the target **2000**) appears in this gate in the odd A channel, sweeping is discontinued to the odd channel, and it is assumed that if a target **2000** appears in one channel it will also appear in the other channel. The target echo has to be present and steady, and the automatic range tracking unit **2020** has to track it for one-half second before the beam riding guidance sub-system **2012** is turned off and the homing error signal is sent to the guidance control system **214.**

If, for any reason, the echo fades or is lost, there is a one-half second memory that continues to send signals to the guidance control system **214** before the homing guidance sub-system **2014** is turned off and the beam riding guidance sub-system **2012** is turned back on. (The guidance systems **2012** and **2014** are not actually turned off. Their outputs are simply switched in or out of the guidance control system **214.**) There is integrated roll control during the homing phase, which limits the roll rates to less than 1° per second. During this time the output of the roll free gyroscope **2790** is disregarded and the sensitivity of the roll rate gyroscope **2063** is increased.

The safety and arming device **132** is used in connection with the fuze **182** to prevent premature detonation of the warhead **194.** Before detonation of the warhead **194** can be effected, this safety and arming device **132** must sustain an acceleration of at least 10 g's for 2½ seconds, (boost) and the preset timer must run down. This time is set into the missile **100** before firing and can be either 9 or 18 seconds. When both of these functions have been met, the switch **4962** is closed completing the electrical circuit between the fuze **182** and the detonators **4800,** and the metal door **4958** in the flame path from the detonators **4800** to the warhead **194** is opened, thus completing arming the warhead **194** at a safe distance from the firing ship.

When the missile **100** comes within the lethal range of the target **2000,** the fuze **182** sets off the detonators **4800,** which, in turn, explode the warhead **194.** Fragments from the warhead **194** upon reaching the target **2000** either destroy or severely damage it.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An aerial missile including, in combination, an airframe comprising a plurality of connected body assemblies having duct sections defining a duct extending throughout the length of the body and having a wall, said wall providing an inlet, a diffuser communicating with the inlet, a combustion chamber communicating with the diffuser and an exit nozzle communicating with the combustion chamber, a cowl lip connecting the forwardmost body assembly and the wall of the forwardmost duct section at their corresponding forward ends, wings on the airframe and mounted for rocking movement about their root axes, longitudinally spaced partitions surrounding the duct wall and defining a compartment, an explosive charge in the compartment and surrounding the duct, a fuze system for the charge, and means mounted on one of the partitions and operable for imparting rocking movement to the wings.

2. An aerial missile as recited in claim **1,** wherein said means includes a plurality of hydraulically operated wing actuators, one of said actuators being provided for each said wing, a source of hydraulic fluid under pressure connected to said actuators, means for controlling flow of fluid to said actuators in response to an electrical signal, and links mechanically connecting the actuators to the wings.

3. In combination with an aerial missile having an airframe including a center body assembly, wings mounted for rocking movement on said body assembly, and means for boosting the missile to supersonic speed; hydraulically operated means within the missile and operable for imparting movement to the wings, said hydraulically operated means including a source of hydraulic fluid, a pump, a plurality of wing actuators, a turbine for operating the pump, means for supplying air under pressure to the turbine during flight of the missile, linkages connecting the actuators with the wings, valve means for controlling fluid flow to the actuators, and electrically operated means for controlling the valve means.

4. In combination with an aerial missile having an airframe comprising connected body assemblies, wings mounted for rocking movement on one of the body assemblies, guidance apparatus in the missile and producing electrical voltages representing missile position errors, and booster means for accelerating the missile to supersonic speed; hydraulically operated means within the missile and operable for imparting movement to the wings, said means including a source of hydraulic fluid under pressure within the missile, a pump, a plurality of wing actuators, a turbine for operating the pump, means for supplying air under pressure to the turbine during flight of the missile, linkages connecting the actuators with the wings, valve means for controlling fluid flow to the actuators, and electrically operated means connected with the guidance apparatus and responsive to said electrical voltages for controlling said valve means, whereby said actuators will be operated by said fluid flow for shifting the wings to correct for said position errors.

5. The combination recited in claim **3,** including means for locking the wings during operation of the booster means, said wing locking means being releasable upon termination of operation of the booster means.

6. The combination recited in claim **3,** including additionally means for locking the wings during operation of the booster means, said wing locking means including a cylinder mounted in the missile adjacent each wing, said wing having a recess, a locking pin having a piston movable in the cylinder, a spring normally urging one end of the pin into the recess for locking the wing, a solenoid operated valve, fluid connections between the solenoid operated valve, the cylinder and the hydraulic means, a source of electric power for the solenoid valve, and means for connecting said electric power source to the solenoid of the solenoid operated valve for opening said valve upon separation of the booster means from the missile whereby fluid will flow to the cylinder for shifting the piston against the compression of the spring and withdrawing the locking pin from the recess for unlocking the wing.

7. The combination recited in claim **6**, including additionally means operable for releasing the wings, whereby said wings may be detached from the body assembly.

8. In an aerial missile having an airframe and a body assembly, and wings mounted for rocking movement on the body assembly; means for mounting said wings for quick detachment from the body assembly, said means including a wing mounting bulkhead in the body assembly for each wing, a wing retaining sleeve in the bulkhead, each said wing having a spar mounted in the sleeve, a bearing rotatably connecting the sleeve with the bulkhead, tongues on the sleeve, and latches on the body assembly and engageable with the tongues.

9. The combination recited in claim **4**, wherein said last mentioned means includes torque motors for said valve means, each of said torque motors comprising an armature, and a pair of coils surrounding the armature, said armature being movable in one direction by energization of one of said coils and being movable in the opposite direction by energization of the other of said coils.

10. The combination recited in claim **4**, wherein said missile airframe includes an inner body mounted within the forwardmost body assembly at its forward end, and said hydraulically operated means includes an accumulator mounted in said inner body.

11. An aerial missile including, in combination, an airframe including forward, center, and aft body assemblies each having a wall defining a duct section, said assemblies being connected in alignment whereby the duct sections thereof will define a continuous duct extending throughout the length of the missile, the wall of the duct being shaped to define an inlet, a diffuser, and an exit nozzle, and a combustor in the duct within the center and aft body assemblies and including an outer shroud, a central can within the outer shroud, a pilot fuel injector assembly surrounding the central can at its forward end and fuel supply means extending into the combustor and connected to the pilot fuel injector assembly.

12. An aerial missile as recited in claim **11**, including additionally fuel injector means in the central can, a source of fuel in the missile and positioned about the center body assembly, means connecting the fuel source with the fuel injector means, and fuel igniter means in the combustor.

13. A hydraulic system for a missile having a movable wing and a duct, comprising, a pump in the missile, a turbine in the missile and operable by airflow passing through the duct during flight of the missile, a wing actuator in the missile and including a cylinder, a piston in the cylinder and having a piston rod, linkage means connecting the piston rod to the wing, means connecting the wing actuator to the pump, a source of hydraulic fluid for the pump, the cylinder and for said last mentioned means, said pump forcing said fluid through said last mentioned means into said cylinder for shifting said piston and rod whereby said linkage will be moved for moving the wing, and means connected between said last mentioned means and said cylinder for controlling fluid flow to the cylinder in response to an electric signal.

14. A hydraulic system as recited in claim **13**, wherein said fluid flow controlling means comprises a transfer valve, and a torque motor operatively connected with the valve.

15. A hydraulic system as recited in claim **13**, including additionally means for locking the wing prior to operation of the turbine and pump.

16. A hydraulic system as recited in claim **13**, wherein the wing is formed with a recess at its root end, and including additionally means for locking the wing against movement prior to operation of the turbine and pump, said last mentioned means including a cylinder, a locking pin having a piston movable in the cylinder, and a spring urging the pin into the recess.

17. In a missile having an airframe including a body, and wings mounted for rocking movement on the airframe; a hydraulic system in the missile and operative for imparting rocking movements to said wings, comprising, a turbine in the airframe, a pump driven by the turbine, a sump, a pair of accumulators, hydraulic fluid in the system, wing actuators operatively connected with the wings, one said actuator being provided for each wing and each said actuator including a cylinder, a piston in the cylinder and means connecting the piston with the wing; fluid conductor means, and electrically operated valve means, said fluid conductor means being connected between the pump, accumulators, sump, wing actuators and valve means, operation of the pump causing fluid flow to the actuator cylinders under control of said valve means.

18. The structure recited in claim **17**, wherein said electrically operated valve means includes a transfer valve, and a torque motor for operating the transfer valve.

19. In an aerial missile having an airframe comprising a plurality of connected body assemblies each having a duct section, said duct sections defining a continuous duct for the missile, said continuous duct including a diffuser, a combustion chamber and an exit nozzle; a combustor in the combustion chamber and including an outer shroud, a central can mounted axially within the outer shroud, a pilot fuel injector assembly mounted within the upstream end portion of the outer shroud and surrounding the upstream end of the central can and fuel supply means mounted axially of the combustion chamber and connected to the pilot fuel injector assembly.

20. A combustor for an aerial missile, comprising, an outer shroud, a central can mounted axially within the outer shroud, a pilot fuel injector assembly mounted within the outer shroud and surrounding a portion of the central can, and fuel distribution means extending into the combustor axially of the shroud assembly and connected to the pilot fuel injector assembly.

21. A combustor as recited in claim **20**, including igniter means extending into the outer shroud in the vicinity of the fuel distribution means.

22. A combustor for an aerial missile, comprising, a frusto-conical outer shroud, a central can mounted in the outer shroud, a pilot fuel injector assembly mounted concentrically within the outer shroud, pilot fuel injector means connected with the pilot fuel injector, main fuel injector means, and means mounting the pilot injector means and main injector means in spaced relation to each other within the shroud.

23. A combustor for an aerial missile, comprising, a frusto-conical outer shroud having a downstream end presented away from a fluid flow, a central can within the outer shroud, a pilot fuel injector assembly mounted concentrically within the upstream end portion of the shroud and surrounding one end of the central can, fuel distribution means connected to the pilot fuel injector assembly near one end thereof, main fuel injector means within the pilot fuel injector assembly and extending downstream of the pilot fuel injector means assembly, fuel supply means for said pilot fuel injector assembly and for said main fuel injector means, and igniter means mounted in the shroud upstream of the pilot fuel injector means.

24. In combination with a aerial missile having an airframe having a diffuser, a combustor in the airframe downstream of the diffuser, and fuel injector means in the combustor; a fuel system comprising a fuel tank, first fuel pressurization means in the missile and connected with the tank for initially pressurizing fuel in the tank, a second fuel pressurization means in the missile for pressurizing fuel in the tank during flight of the missile and after decay of pressure from said first fuel pressurization means to a predetermined value, said second fuel pressurization means including a scoop mounted to receive air flow passing through the diffuser during missile flight, a pump, a turbine connected with the pump for driving said pump, means connecting the pump with the scoop, and means for connecting the pump with the fuel injector means, operation of the pump supplying fuel to the injector means during flight of the missile.

25. The combination recited in claim **24** including additionally fuel regulator means connected with the pump, said last mentioned means and the fuel injector means.

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