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ADVANCED ANTI-TORQUE CONCEPTS STUDY

By

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August 1971

**EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
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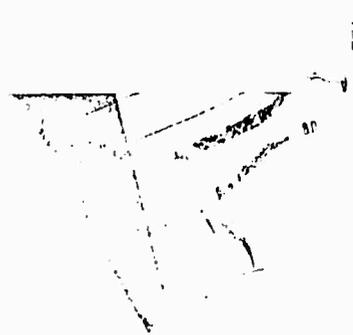
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<p>A design study has been conducted by the Lockheed-California Company on advanced anti-torque concepts intended to replace tail rotors on conventional single-main-rotor/tail-rotor helicopters. The principal design objectives were to reduce hazard to ground personnel and to reduce vulnerability of helicopters to terrain-contact damage. Secondary objectives were reduced vulnerability to small-arms fire and improvements in dynamic, reliability, maintainability and noise characteristics. Two systems were selected from a broad literature search and subsequent design studies. The first concept is based on a main-rotor-driven axial flow fan internally mounted in the aft fuselage delivering air under pressure to a variable geometry louvered exit for anti-torque and/or forward-flight propulsion thrust. The second concept employs a main-rotor-driven ducted fan installed in a central pylon supporting a twin-fin empennage.</p> <p>Results of preliminary design studies applying these concepts to an existing Lockheed Model 286 helicopter are presented in this report, including performance and weight data.</p> <p>Improvements over the research vehicle that could result from applying these concepts to a totally new vehicle, using current state-of-the-art design technology, are also discussed.</p>		

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SUMMARY

A design study has been conducted by the Lockheed-California Company on advanced anti-torque concepts intended to replace tail rotors on conventional single-main-rotor/tail-rotor helicopters. The principal design objectives were to reduce hazard to ground personnel and to reduce vulnerability of helicopters to terrain-contact damage. Secondary objectives were reduced vulnerability to small-arms fire and improvements in dynamic, reliability, maintainability and noise characteristics. Two systems were selected from a broad literature search and subsequent design studies. The first concept is based on a main-rotor-driven axial flow fan internally mounted in the aft fuselage delivering air under pressure to a variable geometry louvered exit for anti-torque and/or forward-flight propulsion thrust. The second concept employs a main-rotor-driven ducted fan installed in a central pylon supporting a twin-fin empennage.

Results of preliminary design studies applying these concepts to an existing Lockheed Model 286 helicopter are presented in this report, including performance and weight data.

Improvements over the research vehicle that could result from applying these concepts to a totally new vehicle, using current state-of-the-art design technology, are also discussed.

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LIST OF SYMBOLS

A	πR^2 , sq ft
A_{Louv}	Lateral area of louvered exit, internal-fan version (20 inches high, 30 inches long), sq ft
B	Tip loss factor; tip fraction of R at which blade lift is considered to become zero
C_T	Thrust coefficient = $T/(\pi R^2) \rho (\Omega R)^2$
D	Main rotor diameter (2R), ft
J_{ψ}	Helicopter yawing moment of inertia, slug-ft ²
Q_{MR}	Main rotor torque, ft-lb
R	Blade tip radius, ft
$\text{SHP}_{\text{F/F}}$	SHP in the fan shaft of a fan-in-fin = $\text{SHP}_{\text{F\&F ind}}$ + $\text{SHP}_{\text{F/F prof}}$, horsepower
$\text{SHP}_{\text{F\&F ind}}$	Induced power of the fan and fin shroud system, horsepower
$\text{SHP}_{\text{F/F prof}}$	Profile power of the fan of a fan-in-fin, horsepower
SHP_i	Induced power of a tail rotor, horsepower
$\text{SHP}_{\text{IF ind}}$	Induced power associated with the lateral thrust from an internal fan, horsepower
$\text{SHP}_{\text{IF prof}}$	Profile power of an internal fan, horsepower
$\text{SHP}_{\text{IF duct}}$	Duct power loss of an internal fan system, horsepower
SHP_{MR}	Main rotor shaft horsepower
SHP_o	Profile power of a tail rotor, horsepower

SHP_{total}	Engine SHP, horsepower
SHP_{TR}	Tail rotor SHP = $SHP_i + SHP_o$, horsepower
T_{Fan}	Thrust of the fan in a fan-in-fin system, lb
T_{TR}	Thrust of a tail rotor, lb
$T_{TR_{35 Kn side wind}}$	Thrust of a tail rotor to achieve helicopter lateral trim in a 35-knot side wind, lb
T_{Fin}	Fin lateral force (not fan shroud in fan), lb
T_{CT}	Lateral force at tail rotor to balance Q_{MR} , lb
T_{IF}	Lateral thrust from internal fan, lb
$T_{F\&F}$	Lateral thrust of the fan and fan shroud system, lb
V	True airspeed, kn
W	Gross weight, lb
X_0	Inboard fraction of R at which blade lift is considered to become zero
b	Number of blades
c	Blade chord, ft
c_l	Two-dimensional lift coefficient
\bar{c}_l	Mean blade lift coefficient
c_d	Two-dimensional drag coefficient
c_{l_i}	Design lift coefficient
$c_{l_{max}}$	Maximum value of c_l

f_o	Equivalent parasitical flap plate area ($C_D = 1$), sq ft
h	Height of skids above the ground, ft
l_{TR}	Distance between centers of main and tail rotors, ft
n	Ratio of the induced velocity at the exit of the fan-in-fin shroud, to v_{fan}
t/c	Thickness ratio of airfoil section, percent
v	Induced velocity of flow normal to the plane of the tail rotor at the plane of the tail rotor, ft/sec
v_{fan}	Induced velocity of flow normal to the plane of the fan-in-fin at the plane of the fan, ft/sec
v_{Louv}	Exit velocity of flow through lateral louvers used with internal fan, ft/sec
ρ	Density of air at altitude, slugs/cu ft
ρ_o	Density of air at sea level, at standard air temperature, slugs/cu ft
σ	1) Air density ratio = ρ/ρ_o 2) Ratio of blade area to disc area = $bc/\pi R$
δ	Mean blade drag coefficient
Ω	Main rotor rotational speed, rad/sec
ψ	Helicopter yaw displacement, deg
$\partial (N/q)/\partial\psi$	Rate of change of helicopter yawing moment divided by dynamic pressure ($1/2 \rho V^2$) with change in ψ

1. INTRODUCTION

Continued efforts have been made since early in the history of rotary-wing aircraft to develop a satisfactory substitute for the conventional tail rotor of single-rotor helicopters. In the early stages of development, when power plant technology allowed but the slimmest margin of power for hovering flight, the main motivation was the saving of the 8% or 10% of total power required to drive the tail rotor. This percent of power and corresponding loss of lift capacity was of the same order of magnitude as the payload. The urgent desire to save this power penalty led to development of several alternatives which, in turn, had their own peculiar drawbacks. With the advent of turbine engines, the critical power situation improved. However, as helicopters became fully operational in combat operations, other tail rotor problems became the source of serious concern. One was the alarming number of fatalities occurring during unloading of troops from closely grouped helicopters under combat conditions through inadvertent walking into whirling tail rotors. The other was the increasing attrition of rotary-wing aircraft due to tail rotor loss or damage sustained when striking terrain obstacles when operating in unprepared areas. These problems led to a renewed desire to replace tail rotors, even at some cost in performance. The helicopter industry was invited to bid on a study aimed at the solution of these problems, resulting in the proposed concepts presented in this report.

The ground rules for this study defined five design objectives in the following order of priority:

1. Reduced hazard to ground personnel
2. Reduced vulnerability to ground-contact damage
3. Reduced vulnerability to small-arms fire
4. Reduced susceptibility to high-speed forward flight flapping instabilities
5. Improved reliability, maintainability, noise, erosion, and foreign object damage characteristics

In view of the large number of tail-rotor-type helicopters in the Army aviation inventory, an underlying objective was that the selected tail rotor substitute should be of a nature that could be adapted to existing helicopters by a retrofit modification program at reasonable cost. This, of course, ruled out any approach that required a significant change to the lift or propulsion system.

A secondary objective was to compile an organized source of information and a comprehensive listing and description of anti-torque devices that have been studied, proposed, or invented.

In carrying out the study, the results of which are presented in the following sections of this report, the work was broken down into the following distinct tasks:

1. Literature search.
2. Tabulation, analysis, and evaluation of concepts, and selection of optimum concept(s).
3. Design studies of selected concept(s) as applied to the Model 286 helicopter.
4. Brief study of gains obtainable by applying the selected concept to a totally new optimized vehicle.

2. SURVEY OF POTENTIAL CONCEPTS

A literature search was made to provide the maximum possible background from which to identify or formulate candidate concepts that could supply anti-torque forces and eliminate the problems that are now associated with tail rotors, without seriously degrading performance, reliability, maintenance, and other desirable features of the tail rotor.

Initially, the search was directed at anti-torque devices for conventional single-rotor shaft-driven helicopters. As the task progressed, the search was broadened to include a wide variety of schemes for producing forces or moments. Altogether, 97 concepts were identified as potential candidates.

It became evident during the search that many concepts had similar basic characteristics which permitted grouping them into the following categories:

- Conventional tail rotors
- Ducted fans
- Nozzles
- Immersed aerodynamic surfaces
- Horizontal-axis rotary-wing airfoils
- Future concepts

A brief discussion of each category is given here. More detailed descriptions of concepts uncovered in the search are given in the appendix.

CONVENTIONAL TAIL ROTOR

The conventional tail rotor was used as a baseline for comparison with other concepts. In general, it is mounted at the aft end of the fuselage structure and exerts thrust 90 degrees to the centerline of the fuselage, it is mounted on one side of the fuselage completely exposed, and it is shaft driven from the main-rotor gearbox.

Related to the tail rotor are various propeller arrangements found in the literature search; for example, a 90-degree rotatable pusher propeller that can be used for both thrust and anti-torque. An auxiliary propeller mounted on one wing tip was suggested for anti-torque control, but since this offers no improvement in safety over a conventional tail rotor, and is applicable only to winged helicopter designs, it was not studied. Examples of other similar concepts that were discarded for similar reasons are:

1. Twin tail rotors, opposed and inclined 45 degrees.
2. Twin rotors mounted on each wing tip with their centerlines of rotation oriented fore and aft.

Various versions of the tail rotor and propeller concept are included in the literature search summary in the appendix.

DUCTED FANS

This anti-torque device is usually submerged within the vertical tail or the tail cone and is shaft driven off the main rotor to permit operation during engine-out, autorotation conditions. Essentially the same drive train used for conventional tail rotors is used. Collective pitch of the fan blades is provided to modulate thrust. Thrust requirement is traded off with disc loading, drag, efficiency, and weight to obtain an optimum size fan for a particular vehicle.

Use of a direct supply of hot gas from the engine to serve as a turbo-fan driving medium was ruled unacceptable in gathering concepts from the literature because of inability to operate during engine-out conditions.

Small fan designs have been incorporated in test vehicles as anti-torque devices with considerable success. A production version of this application is on the Sud Aviation SA 341 "Gazelle." Known as the "Fenestron," this shrouded tail rotor, or ducted fan, operates at 5774 rpm, has 13 blades and has a fan diameter of 696 mm (27-13/32 in.). The shroud improves the efficiency, but the small diameter degrades propulsion efficiency, compared to a conventional (exposed) rotor, by about 3.3 percent of total engine power or 12 HP. This relative inefficiency applies to the hover condition only. In forward flight, the vertical fin (with twist and camber) provides most of the anti-torque force.

Lightly loaded large-diameter ducted fans with restrained tips are considered as possible extensions of those concepts found in the literature. Propulsion efficiency can be improved, but aerodynamic drag would be penalized due to relatively large frontal areas. These characteristics must be traded off for a particular design. A compromise design in the form of an intermediate disc loading fan could be the optimum for many vehicles.

All fans improve the forward flight performance relative to an exposed rotor due to the reduction in vehicle drag when the fin provides the anti-torque force in forward flight.

Several ducted fan concepts are included in the literature search summary in the appendix.

NOZZLES

Several types of nozzle devices suitable for anti-torque application were identified in the search. The nozzle can be single and rotatable, or two opposed nozzles may be used. Modulation of thrust can be accomplished by adjusting the throat or by varying the upstream plenum pressure. Plenum pressure can be supplied by a compressor driven by the main rotor. Another source of power identified showed main engine high-pressure exhaust gases routed directly to the nozzle. However, this concept is not attractive due to low thermodynamic efficiency and lack of operating capability during engine-out conditions.

A unique nozzle arrangement found in the search suggests an array of aspirators ejecting high-pressure air which induces a secondary flow of outside air through concentric nozzles.

Several nozzle type devices are included in the literature search summary in the appendix.

IMMERSED AERODYNAMIC SURFACES

Aerodynamic surfaces have often been considered for providing anti-torque forces by acting as airfoils immersed in the wake of an airflow generator such as the helicopter main rotor or pusher propeller. They fall in two general categories: those primary systems which can be designed to produce the entire anti-torque moment; and those auxiliary systems which generate forces to supplement other anti-torque devices.

A basic concept for an anti-torque device which is best applied as a supplementary system is a fixed airfoil in the main rotor downwash, oriented to generate thrust in the direction to produce main rotor anti-torque. By making this surface movable, a modulating anti-torque and lateral control system is accomplished.

Auxiliary systems using two or more surfaces below the main rotor have been proposed. However, as a rule these systems were unwieldy, impractical arrangements. One example was an array of aerodynamic surfaces positioned around the aircraft; in such an arrangement, visibility is inhibited, drag is increased, controls are complicated, and the system is ineffective in autorotation.

A fuselage completely contoured for anti-torque was suggested, but was also considered impractical: internal space is penalized, and the system is ineffective during engine-out and autorotation conditions.

Surfaces used in conjunction with a thrusting device have been configured into primary anti-torque systems. In the case of a compound vehicle, for example, the pusher propeller can move air over a rudder positioned immediately aft of the propeller.

A more unusual approach makes use of the Magnus effect to obtain a net side force. This can be done with a rotating aft fuselage shell, or with a stationary aft fuselage shell which has tangential slots to eject high-pressure air. In either case, a vortex flow component is generated to create a net force in the lateral direction.

Many concepts in this category are also included in the literature search summary in the appendix.

HORIZONTAL-AXIS ROTARY-WING AIRFOILS

A distinct general type of anti-torque system employs airfoils rotating about a horizontal axis parallel to the spanwise direction in paddle-wheel fashion, and often referred to as a "cyclo-gyro". The axis of rotation is generally in the fore-and-aft direction, and cyclic pitch controls the direction and magnitude of the anti-torque force. This type is generally penalized by complex design and high drag.

FUTURE CONCEPTS

A number of advanced concepts were examined that are outside the present state-of-the-art. They are included for completeness in covering the full spectrum of anti-torque concepts. Furthermore, consideration of highly advanced concepts, which must be preceded by fundamental research, is consistent with the philosophy that basically new concepts must be developed to enable vertical lift technology to progress dramatically. An example of such philosophy is recorded in the U. S. Army Advanced Materiel Concepts Agency's Ad Hoc Report 6, "Aerial Very Heavy Lift Concepts for the 1990 Army", which states (in part) "---electromagnetic forces were mentioned as a possibility. It was generally agreed that, today, such devices --- serve only as interesting demonstration devices. However, by the 1990 time period, advances in technology may make them more attractive for practical application". In line with this reasoning, concepts of "far out" mechanisms (not necessarily mechanical in a hardware sense), conceivably capable of generating substantial forces or torques, are included here. Development of these systems would yield the possibility of major breakthroughs in force-generating systems, not only for anti-torque purposes, but also for lift and propulsion.

When studied in detail, the concepts presented in this category may show an apparent conflict with time-honored conservation laws, as well as the action-reaction principle. This, however, should not be particularly disturbing since, for example, nuclear physics has shown that absolute conservation of mass and absolute conservation of energy are not longer inviolate laws. Likewise, the action-reaction assumption expressed in Newton's third law, although generally valid for two infinitesimal, infinitely rigid particles, admittedly does not hold for magnetic interactions between moving charges (see Figure 77, and page 139 of Ref. 6-2). In the manner that purely "mechanistic" theories are not directly applicable in the realm of subatomic micro-phenomena of the Quantum Theory nor in the large-scale

macro-phenomena of the Theory of Relativity, it is not inconceivable that important exceptions to the traditional laws of physics may exist in the vast middle ground of engineering between subatomic and intergalactic dimensions, with practical applications of unmeasured possibilities. Possible examples of this type of concept, described in some detail in the appendix, and the subject of private experimental research by the author over a period of years, include:

Electromagnetic rotation

Acoustic radiation pressure

Three-dimensional vortex

Compound precession of multiple gyroscopes

3. CONCEPT SELECTION

The screening of concepts during the literature search eliminated a few concepts which were considered either nonapplicable or clearly impractical. All the remaining candidates were then classified into one of 17 types characterized by special arrangements of the 6 categories in the preceding section. These 17 types were in turn grouped into three major classifications: Present State-of-the-Art, Advanced Technology and Existing Tail Rotors. The Present State-of-the-Art systems were further grouped into primary systems and auxiliary systems. This general grouping is summarized in Table I. The 17 types were then subjected to a scoring process by use of a scoring matrix in which each type was graded on a number of desired characteristics from which a total weighted score was obtained for each type. The conventional tail rotor was included to provide a baseline for comparison purposes. Scoring matrices are shown in Table II.

The scores shown in the matrices are results of detailed evaluations. They are based on grading of desirable characteristics shown as the column headings. Since the primary design objective was to eliminate the hazard to ground personnel and the susceptibility to terrain contact damage, weighted scores reflect an emphasis on these requirements. For instance, ground personnel safety has a maximum possible "weighted" score of 15, whereas the maximum score possible for minimum hover power is only 2. Each characteristic of each concept is given a grade expressed in percent. The weighted score points awarded for each characteristic are obtained as the product of the grade ($\div 100$) times the maximum possible score points for that item.

Two broad areas of weighting scores were defined: economy and effectiveness. Evaluating economy leads to one subtotal and evaluating effectiveness leads to another. This arrangement is useful to identify concepts that might require high development cost but could have favorable functional effectiveness once developed. Such concept might be a good candidate for further research. On the other hand, a concept reflecting low development cost and low effectiveness might not merit further development effort. Obviously, a high score in both categories indicates a good choice to pursue.

An examination of the total scores on the evaluation matrices reflects the relative merits of all concepts. It was concluded that further development should be recommended for the following concepts:

- A main-rotor-driven axial compressor feeding a variable-geometry nozzle generating anti-torque and/or forward propulsion thrust
- A main-rotor-driven ducted fan of moderate disc loading, buried in a central vertical fin.

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TABLE I. GENERAL ANTI-TORQUE CONCEPT CATEGORIES SELECTED FROM LITERATURE SEARCH FOR COMPARATIVE EVALUATION

I. Present State-of-the Art

a. Primary Systems

1. Fan-in-Fin (compact size)
2. Fan-in-Fin (intermediate disc loading)
3. Fan-in-Fin (lightly loaded with restrained tips and minimum shroud)
4. Laterally displaced propulsion devices (fan or propellers)
5. Tail-mounted swiveling fan (or propeller)
6. Compressor-fed laterally oriented controllable nozzles, with optional forward propulsion
7. Lateral jets augmented by secondary-flow ejector rings
8. Compressor-powered jet exiting from slot nozzle along controllable trailing edge of vertical fin
9. Horizontal-Axis Rotating-Wing Aerodynamic Systems
10. Movable airfoils (vanes) in wake of forward thrusting device

b. Auxiliary Systems

1. Airfoil surfaces in main rotor downwash
2. Forced circulation around tail boom by tangential jets (or surface rotation) interacting with main rotor downwash

II. Future Technology

1. Force or moment generated electromagnetically utilizing room-temp superconductivity
2. Acoustic radiation pressure in a resonant closed-loop standing-wave system
3. Low pressure area induced on a surface by 3-dimensional vortex
4. Compound precession of multiple gyroscopes

III. Existing Tail Rotors (Ref. Baseline)

REPRESENTATIVE CONCEPTS
FROM LITERATURE SEARCH

EFFECTIVENESS

A. PRESENT STATE OF THE ART

a. PRIMARY SYSTEMS

1. Fan-in-Fin (Compact Size)
2. Intermediate Disc Loading Fan-in-Fin
3. Lightly Loaded Fan-in-Fin With Restrained Tips and Min. Shroud
4. Laterally Displaced Propulsion Devices, Fans (or propellers)
5. Tail-Mounted Swiveling Fan (or propeller)
6. Compressor-Feeding Laterally Oriented Controllable Nozzles, with Optional Forward Propulsion
7. Primary Jet as in (6) Above Augmented by Multiple Ejector Rings
8. Compressor-Powered Jet Exiting From Slot Nozzle Along Controllable Trailing Edge of Vertical Fin
9. Horiz. Axis Rotating Wing Aero Systems
10. Movable Airfoils in Wake of Forward Thrust Device

b. AUXILIARY SYSTEMS

1. Airfoil Surfaces in Main Rotor Downwash
2. Forced Circulation Around Tail Boom by Tangential Jets (or Surface Rotation) Interacting with Main Rotor Downwash

	Ground Personnel Safety	Min. Vulnerability to Terrain Contact Damage	Design Simplicity (Maint. Reliability)	Low Noise Signature	Minimum Weight	Minimum Drag	Minimum Hover Power	Minimum Vulnerability to Small-Arms Fire	Hig! Speed Flight Stability	Min. Erosion & Foreign Object Damage	Effectiveness Subtotal	Short RDT&E Time	Low RDT&E
1. Fan-in-Fin (Compact Size)	67	70	50	25	67	67	50	75	75	100	31	80	70
2. Intermediate Disc Loading Fan-in-Fin	93	90	38	50	67	67	75	50	75	100	36	73	60
3. Lightly Loaded Fan-in-Fin With Restrained Tips and Min. Shroud	60	70	38	75	33	50	75	50	75	50	29	67	50
4. Laterally Displaced Propulsion Devices, Fans (or propellers)	53	60	31	25	33	33	25	50	100	100	24	47	50
5. Tail-Mounted Swiveling Fan (or propeller)	80	80	28	50	33	100	75	50	100	100	34½	53	60
6. Compressor-Feeding Laterally Oriented Controllable Nozzles, with Optional Forward Propulsion	100	100	62	75	50	100	75	50	100	100	44	67	50
7. Primary Jet as in (6) Above Augmented by Multiple Ejector Rings	100	90	50	75	33	33	75	75	100	100	39	33	40
8. Compressor-Powered Jet Exiting From Slot Nozzle Along Controllable Trailing Edge of Vertical Fin	100	90	50	50	50	17	50	75	75	100	37	67	40
9. Horiz. Axis Rotating Wing Aero Systems	100	80	50	75	50	33	50	100	100	100	38	53	40
10. Movable Airfoils in Wake of Forward Thrust Device	80	50	38	75	33	33	50	50	100	100	30	33	40
b. 1. Airfoil Surfaces in Main Rotor Downwash	100	80	63	100	17	17	100	100	50	100	39	7	10
b. 2. Forced Circulation Around Tail Boom by Tangential Jets (or Surface Rotation) Interacting with Main Rotor Downwash	100	100	88	75	67	67	50	100	100	100	45	13	20
	15	10	8	4	3	3	2	2	2	1		15	10
	<u>Effectiveness Subtotal</u>										50	<u>Economy</u>	

MAXIMUM SCORE POINTS

TOTAL

TABLE II. ANTI-TORQUE CONCEPT EVALUATION

PRINCIPAL DESIGN OBJECTIVE: IMPROVED SAFETY IN MILITARY OPERATIONS

NOTES: 1.

2.

3.

ECONOMY

Minimum Drag	Minimum Hover Power	Minimum Vulnerability to Small-Arms Fire	High Spee. Flight Stability	Min. Erosion & Foreign Object Damage Subtotal	Short RDT&E Time	Low RDT&E Cost	Minimum Technical Risk	Minimum Mfg. Cost	Low Operating Cost	Economy Subtotal	TOTAL SCORE	COMPARATIVE RATING		
75	75	100	31	80	70	70	70	60	36	67	3	3	Same as SUD Fent	
50	75	100	36	73	60	60	60	80	33	69	2	2	☆	
50	75	50	29	67	50	50	50	40	27	56	8	8		
50	100	100	24	47	50	50	50	40	24	48	10	10	One device must	
50	100	100	34½	53	60	60	60	40	28	62½				
50	100	100	44	67	50	50	50	80	29	73	1	1	☆	
75	100	100	39	33	40	40	30	80	20	59	7	7	Reversing direc	
75	75	100	37	67	40	40	50	60	26	63	4	4	High jet ve.oci	
100	100	100	38	53	40	40	50	40	23	61	6	6		
50	100	100	30	33	40	40	50	40	20	50	9	9		
100	100	50	100	39	7	10	10	50	40	10	49	2		
50	100	100	100	45	13	20	20	50	40	13	58	1		
2	2	2	1	15	10	10	10	5						
Effectiveness Subtotal				50	Economy Subtotal				50	TOTAL SCORE		100		

EFFECTIVENESS

ECONOMY

11a

REPRESENTATIVE CONCEPTS
FROM LITERATURE SEARCH

EFFECTIVENESS

B. FUTURE TECHNOLOGY

1. Force or Moment Generated Electromagnetically Utilizing Room-Temp Superconductivity.
2. Acoustic Radiation Pressures in a Resonant Closed-Loop Standing Wave System.
3. Low Pressure Area Induced on One Side of Vertical Tail by Controlled Three-Dimensional Vortex.
4. Compound Precession of Multiple Gyroscopes.

C. EXISTING TAIL ROTOR (Ref. Baseline)

	Ground Personnel Safety	Min. Vulnerability to Terrain Contact Damage	Design Simplicity (Maint. Reliability)	Low Noise Signature	Minimum Weight	Minimum Drag	Minimum Hover Power	Minimum Vulnerability to Small Arms Fire	High Speed Performance	Min
1. Force or Moment Generated Electromagnetically Utilizing Room-Temp Superconductivity.	67	100	63	100	33	100	100	100	100	100
2. Acoustic Radiation Pressures in a Resonant Closed-Loop Standing Wave System.	100	100	88	50	33	100	100	100	100	100
3. Low Pressure Area Induced on One Side of Vertical Tail by Controlled Three-Dimensional Vortex.	100	100	88	100	68	100	100	100	100	100
4. Compound Precession of Multiple Gyroscopes.	100	100	38	75	33	100	100	50	100	100
C. <u>EXISTING TAIL ROTOR (Ref. Baseline)</u>	7	10	25	50	67	33	100	50	25	50

MAXIMUM SCORE POINTS

15 10 8 4 3 3 2 2 2 1

Effectiveness Subtotal

Preceding page blank

TABLE II. CONTINUED

EFFECTIVENESS									ECONOMY								COMPARATIVE RATING				
Safety	Vulnerability to Main Contact Damage	Design Simplicity (Maint. Reliability)	Low Noise Signature	Minimum Weight	Minimum Drag	Minimum Hover Power	Minimum Vulnerability to Small Arms Fire	High Speed Flight	Min. Erosion & Foreign Object Damage	Effectiveness Subtotal	Short RDT&E Time	Low RDT&E Cost	Minimum Technical Risk	Minimum Mfg. Cost	Low Operating Cost	Economy Subtotal	TOTAL SCORE	COMPARATIVE RATING			
																	0	10	20	30	
3	100	33	100	100	100	100	100	40	7	10	10	30	80	10	50	4					
3	50	33	100	100	100	100	100	45	7	10	10	50	80	12	57	2					
3	100	68	100	100	100	100	100	48	7	10	10	80	80	15	63	1					
3	75	33	100	100	50	100	100	41	33	33	30	20	60	16	57	2					
5	50	67	33	100	50	25	50	13	93	90	90	90	40	43	56	3					
4	3	3	2	2	2	1			15	10	10	10	5								
Effectiveness Subtotal									50	Economy Subtotal					50	TOTAL SCORE				100	

13a

EFFECTIVENESS

TABLE II. CONTINUED

ECONOMY

NOTES: 1. Numbers in the bottom row reflect degree of effectiveness in percent.

2. Numbers in the sub-total columns are the sum of individual products numbers and the resulting score points.

	Minimum Technical Risk	Minimum Mfg. Cost	Low Operating Cost	Economy Subtotal	TOTAL SCORE	COMPARATIVE RATING	0	10	20	30	40	50	60	70	80	90	100
30	80	10	50	4			[Bar chart showing scores for product 4]										
50	80	12	57	2			[Bar chart showing scores for product 2]										
80	80	15	63	1			[Bar chart showing scores for product 1]										
20	60	16	57	2			[Bar chart showing scores for product 2]										
90	40	43	56	3			[Bar chart showing scores for product 3]										
10	5						[Bar chart showing scores for product 5]										
total		50					[Bar chart showing total scores]										
SCORE			100				[Bar chart showing total score of 100]										

EFFECTIVENESS

ECONOMY

13%

The first offers several advantages over the exposed tail rotor. Rotating machinery is completely protected from terrain contact and in no way endangers ground personnel. The noise level is predicted below that of the baseline system. The shorter drive shaft and the elimination of the right-angle gearbox simplify the drive systems. Optional supplementary anti-torque force by forced circulation is available at negligible cost.

The second is a refinement or optimization of the ducted fan concept now employed in the SUD 341. The moderate disc loading regime can be shown to maximize performance while not incurring significant weight or drag penalties. The power drive from the main rotor gearbox insures anti-torque operation during engine-out or autorotation conditions. Hazard to ground personnel and susceptibility to terrain-contact damage are minimum. A cambered fin can be designed to supply most of the anti-torque force required in forward flight.

4. PRELIMINARY DESIGN STUDIES

INTRODUCTION

The preliminary design work was conducted as a nearly parallel effort to the concept selection discussed in the preceding section. It was found that although initial preliminary design was guided by the concept selection processes, results of the design investigations not only aided in the concept selection but actually reversed the relative standing of the two leading candidates.

As a consequence, it was decided to select two concepts for detailed study. These two designs, along with the result of brief studies on other concepts that were studied in making the final selection, are discussed below.

BASIC VEHICLE

The preliminary design was based on the premise that the selected concept(s) would be applied to an existing conventional tail-rotor-type helicopter. Furthermore, the application would follow a retrofit modification approach rather than a completely new design. The Lockheed Model 286 was selected as the basic vehicle. A general arrangement is shown in Figure 1, and the internal details are shown in Figure 2. It is conventional in design except for the nonarticulated rigid rotor and associated control system. It is a derivative of the XH-51A helicopter that was designed as a research vehicle. The 286, although FAA certificated was designed principally as a demonstrator. Since it was not intended for production, economic constraints prevented the incorporation of some design refinements and minimum-weight detail design. With a design gross weight of 4700 pounds and a 550 SHP turbine engine, the weight empty of 3000 pounds yields a rather high weight-empty fraction. The disc loading of 4.9 psf is somewhat low by current practice. Flying qualities, however, are excellent, and structural integrity has been amply demonstrated. It is therefore considered to be an ideal vehicle for a research program on the anti-torque concepts under consideration.

INTERNAL FAN CONCEPT

The general arrangement of this concept as applied to an existing Lockheed Model 286 is shown in Figure 3. The internal arrangement is shown in the inboard profile drawing, Figure 4. This concept was derived from other concepts often referred to as "tail cone fan" or "lateral jets fed by rotor-driven compressor". Those concepts were penalized by high jet velocities, high drag in forward flight due to blunt aft end, high noise level, and excessive power requirements. A study showed, however, that by applying compound-helicopter technology to this concept, substantial advantages could be obtained, principally those resulting from auxiliary forward flight

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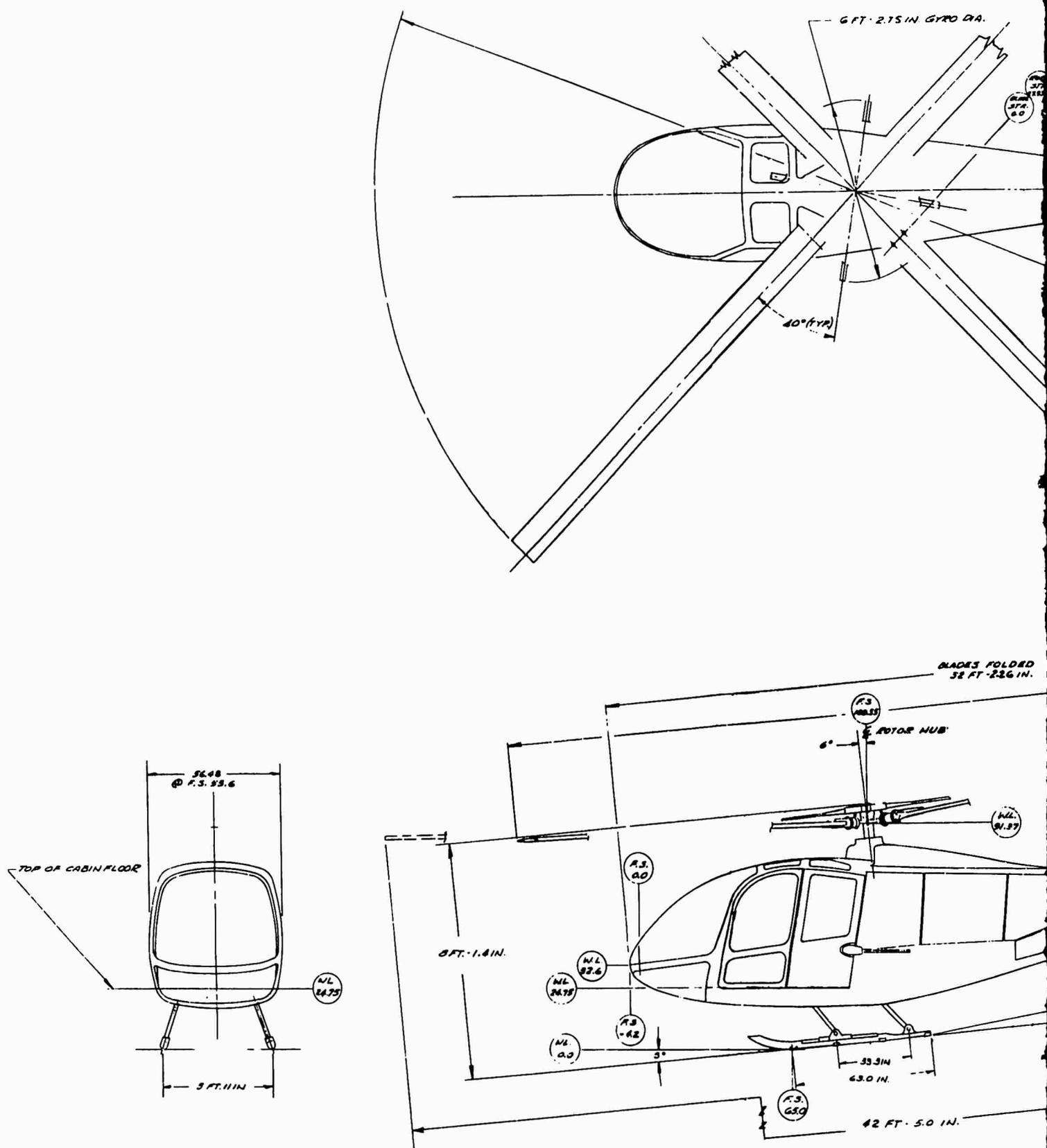
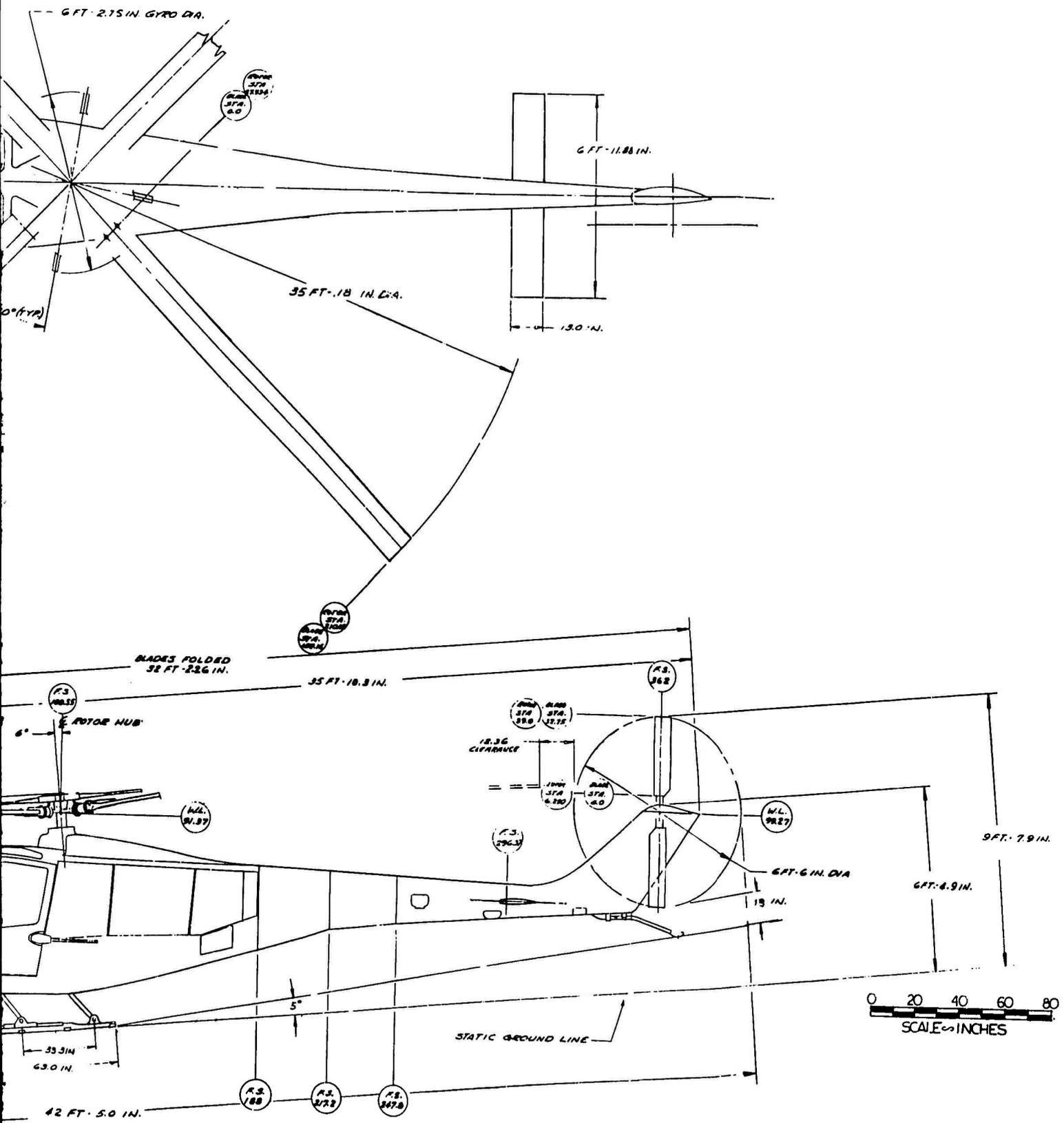


Figure 1. General Arrangement - Model 286.

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19a

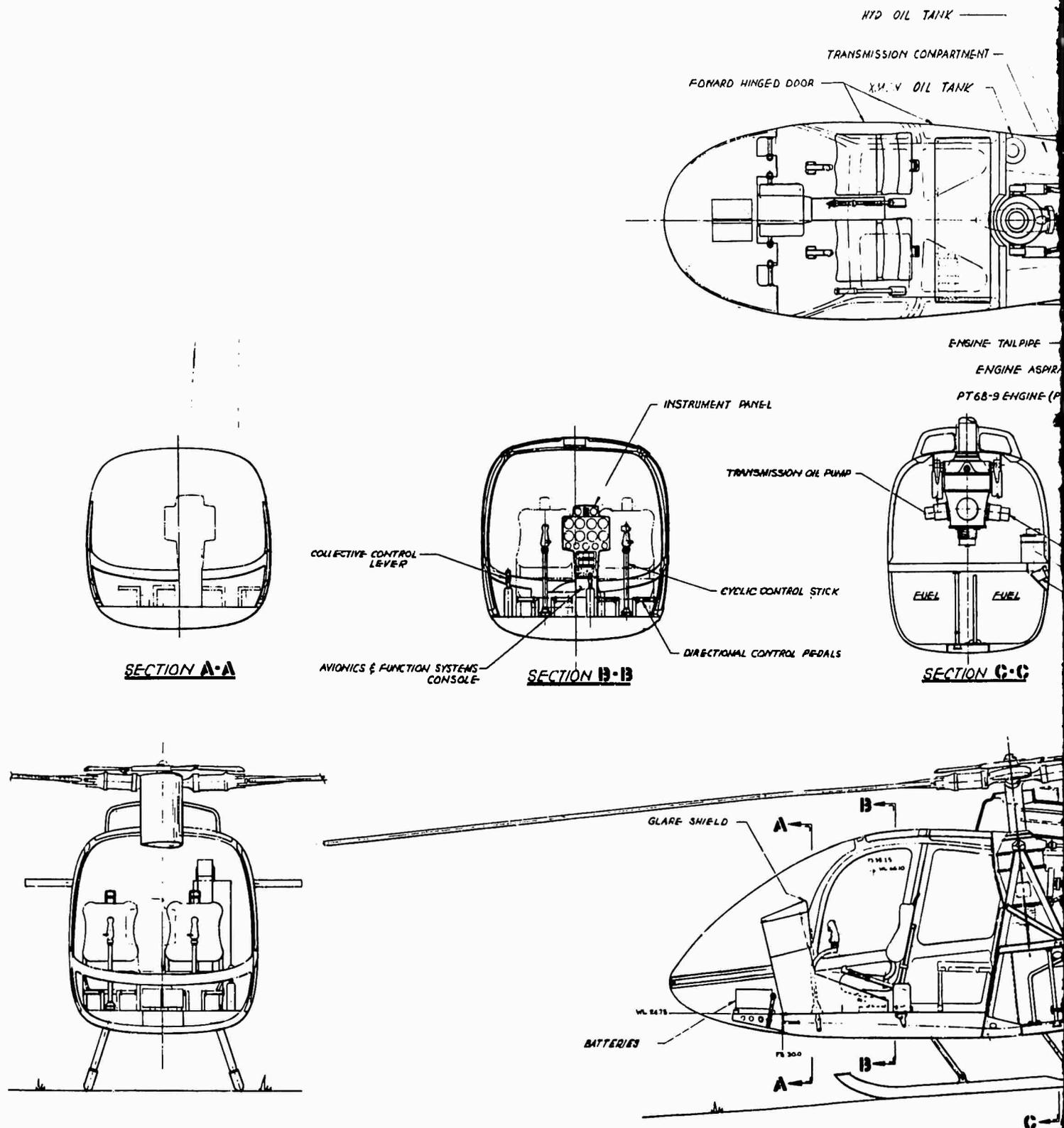
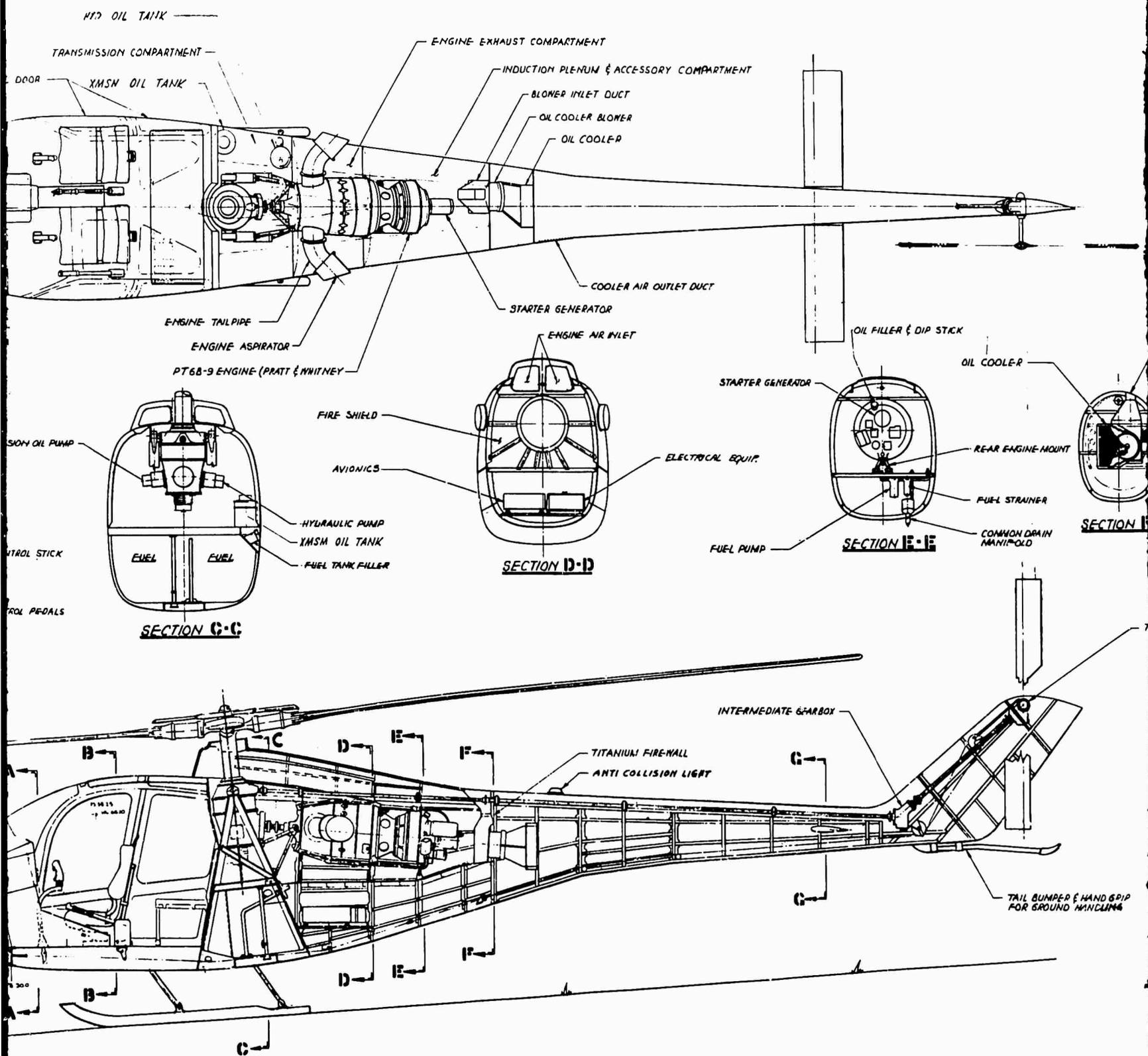
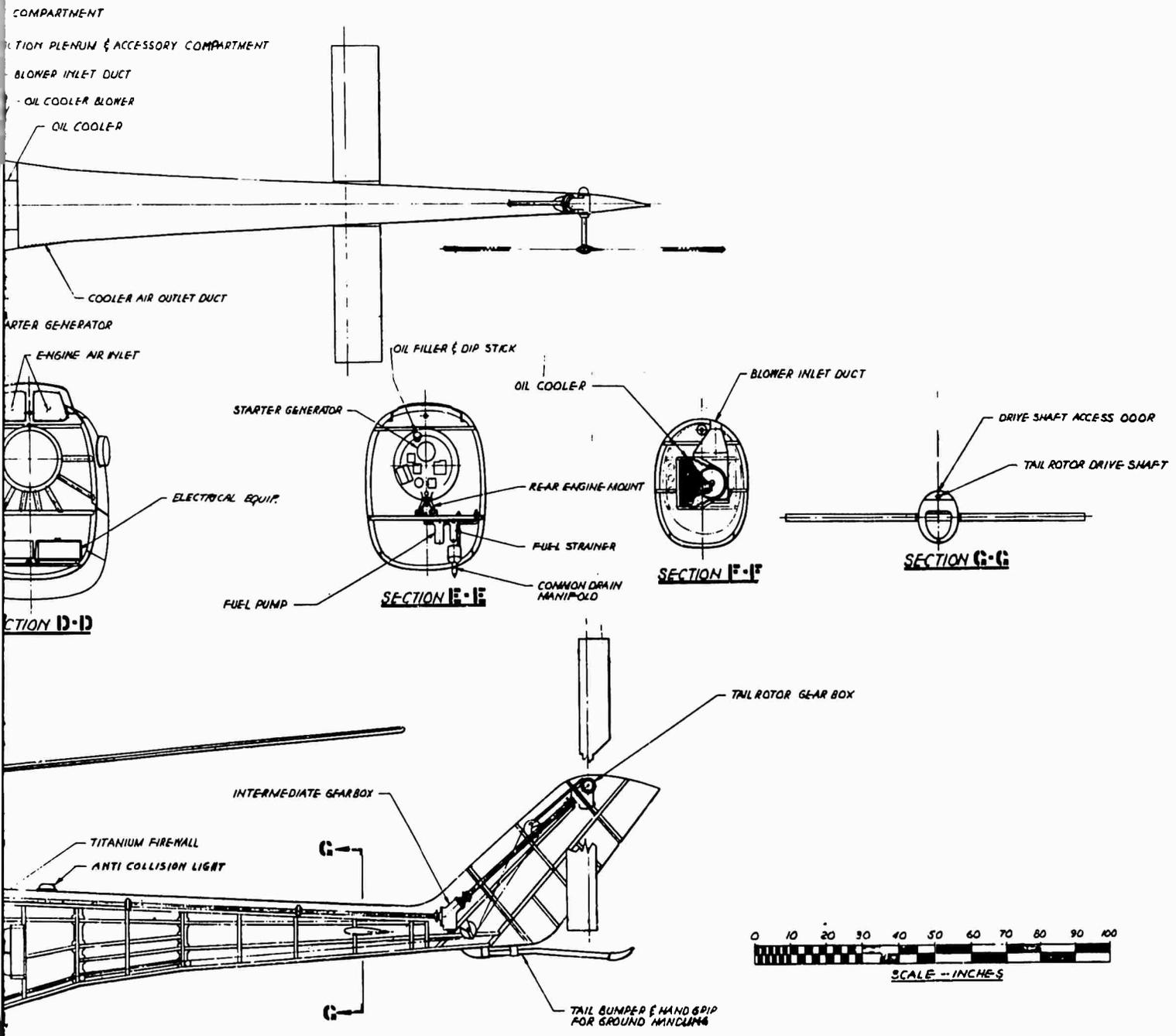


Figure 2. Inboard Profile - Mode 286.

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21a



21 R

MAIN ROTOR

DIAMETER 35. FT.-0. IN.
CHORD 13.5 IN.
DISC AREA 962. SQ.FT.
TIP SPEED-NORMAL - 650. FT/SEC.

HORIZONTAL TAIL

AREA 16.3 SQ.FT.

VERTICAL TAIL

AREA 18.8 SQ.FT.

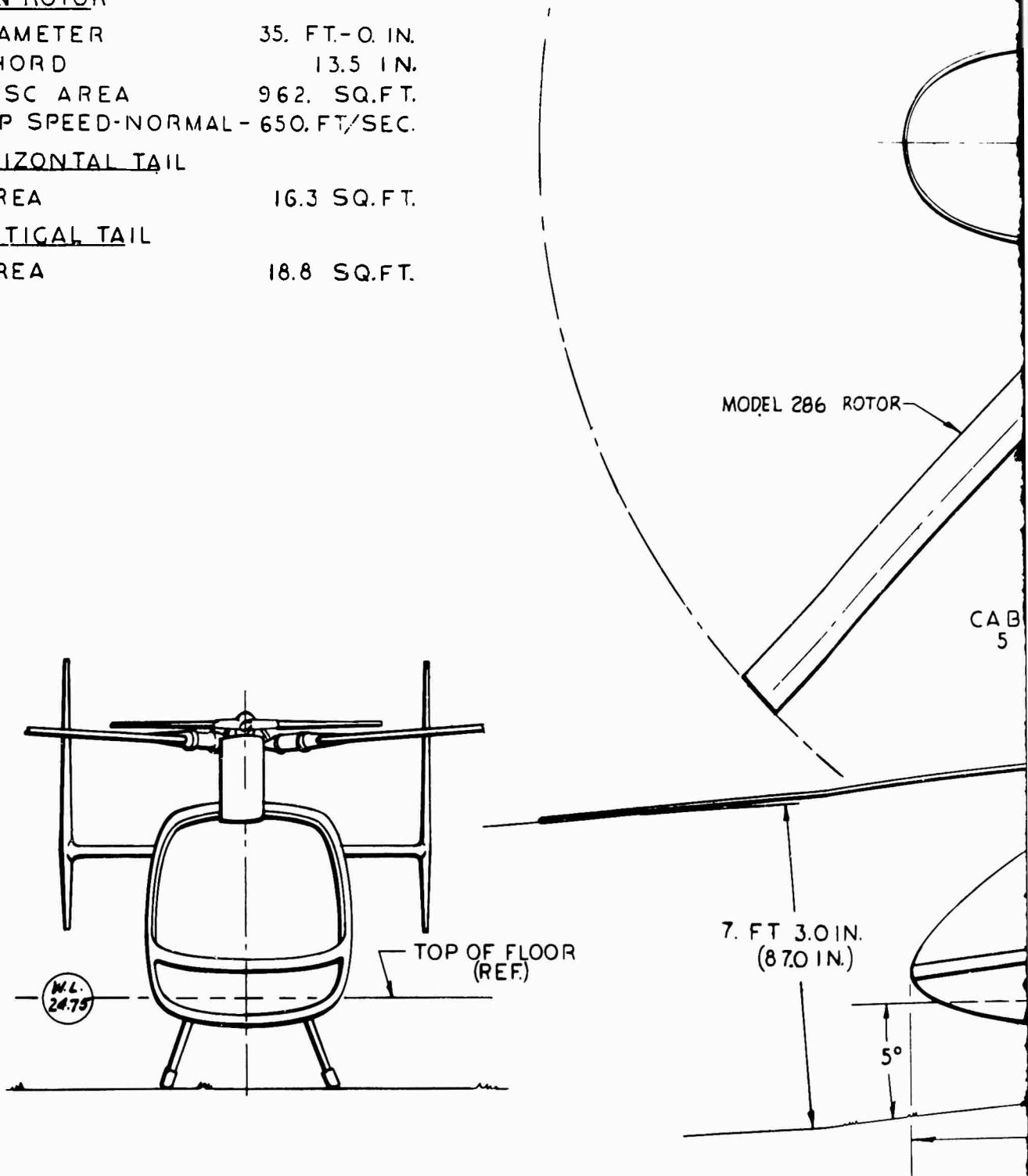
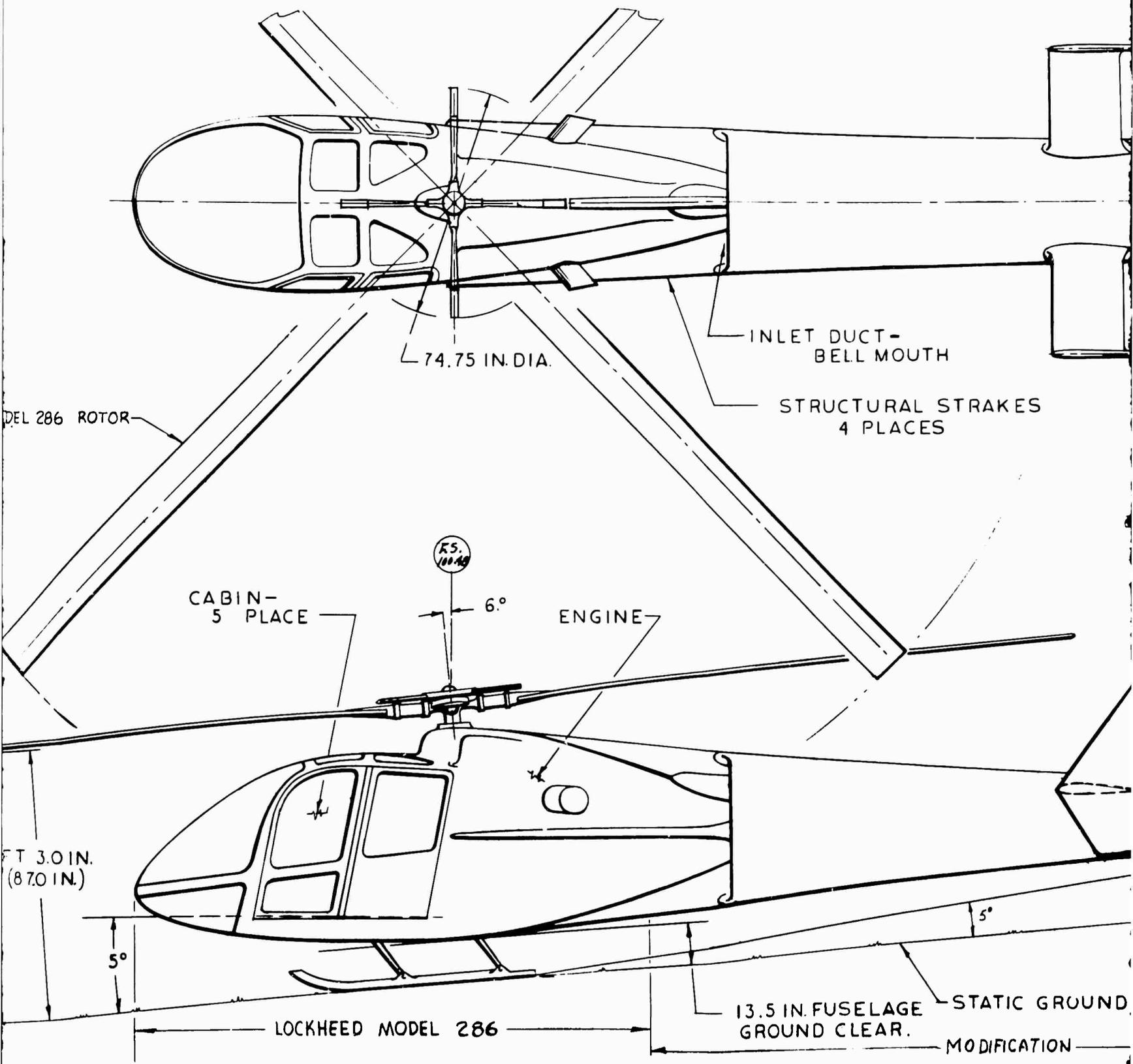
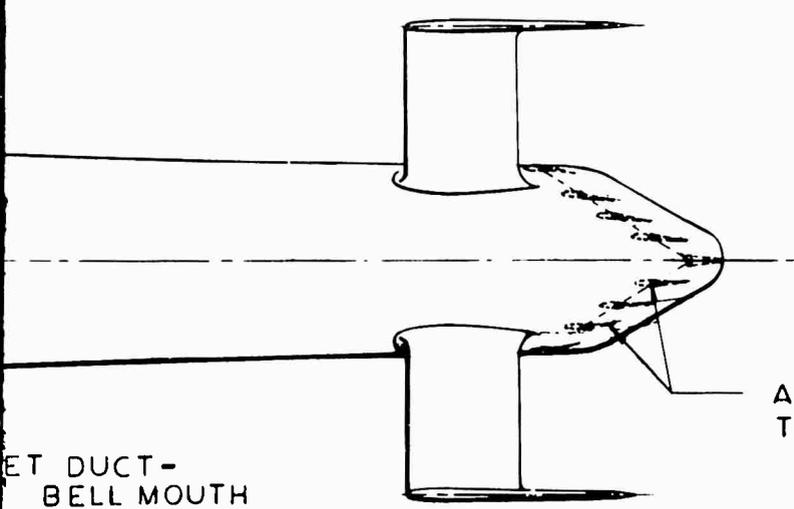


Figure 3. General Arrangement - Internal Fan Concept.



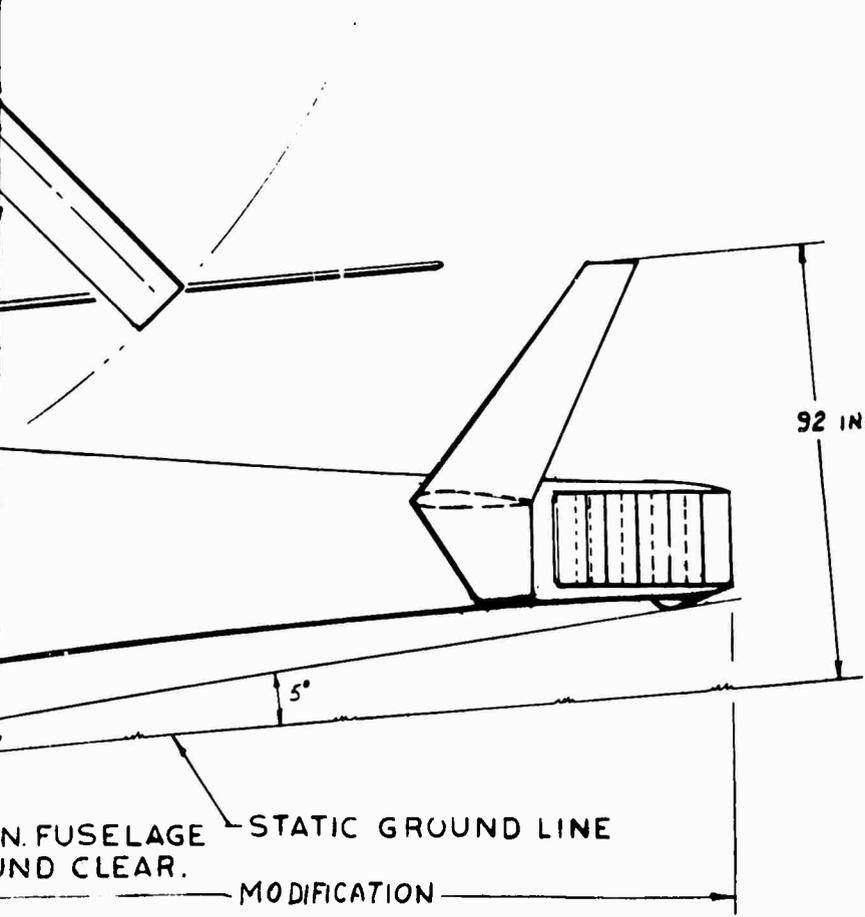
23a



ANTI-TORQUE, YAW, AND FORWARD THRUST VARIABLE GEOMETRY VANES (CL-1095-8-3)

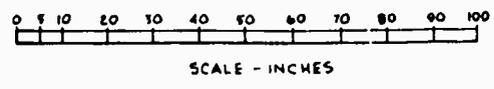
JET DUCT - BELL MOUTH

STRUCTURAL STRAKES 4 PLACES



92 IN.

5°



IN. FUSELAGE AND CLEAR. - STATIC GROUND LINE
 - MODIFICATION

234

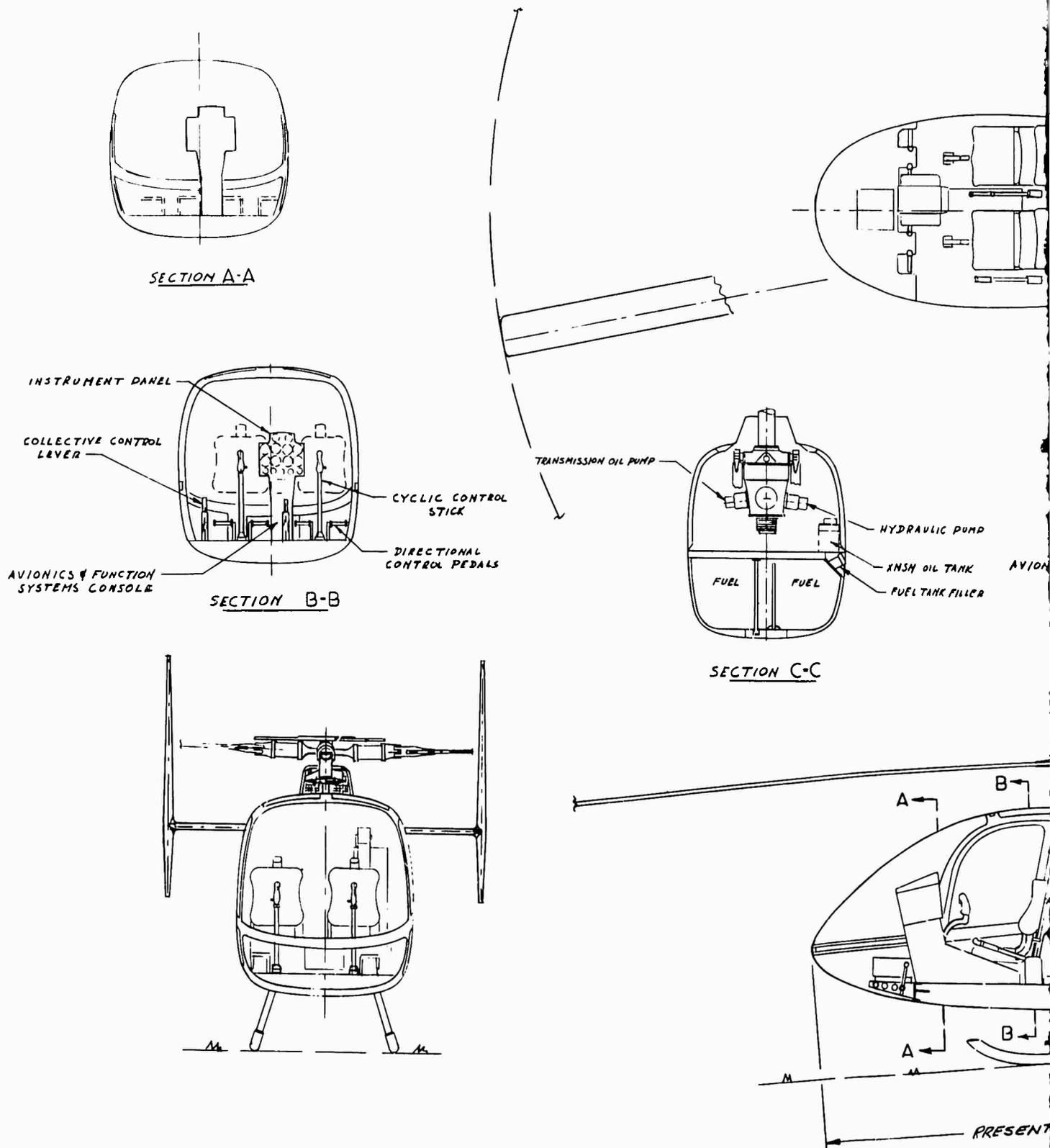
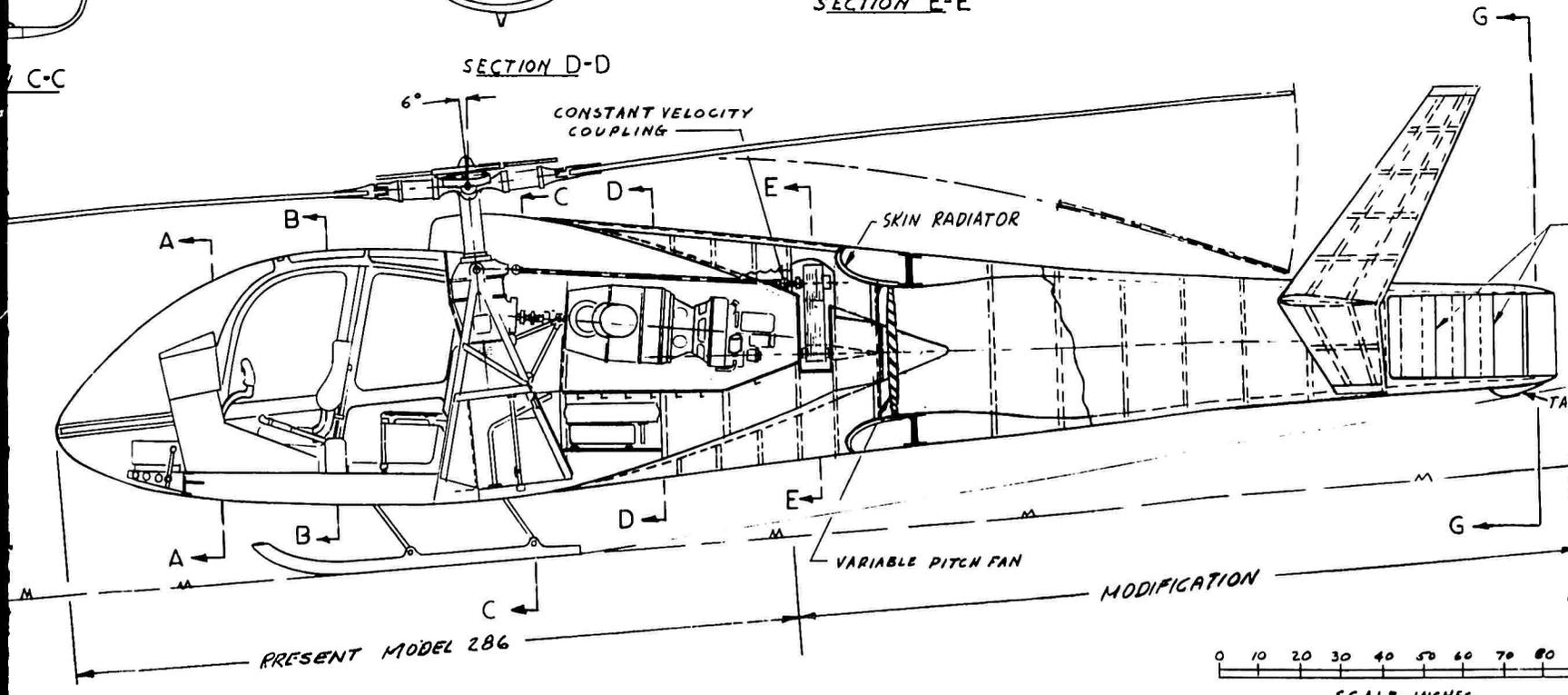
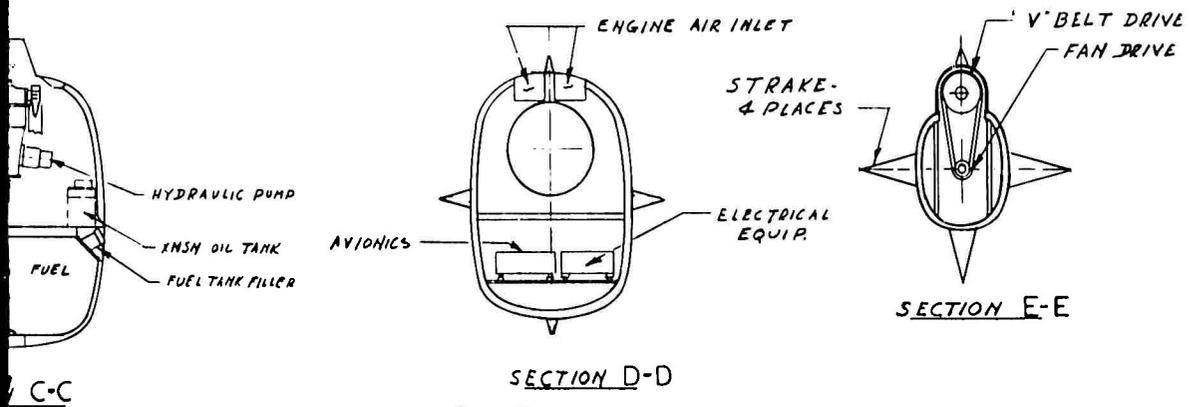
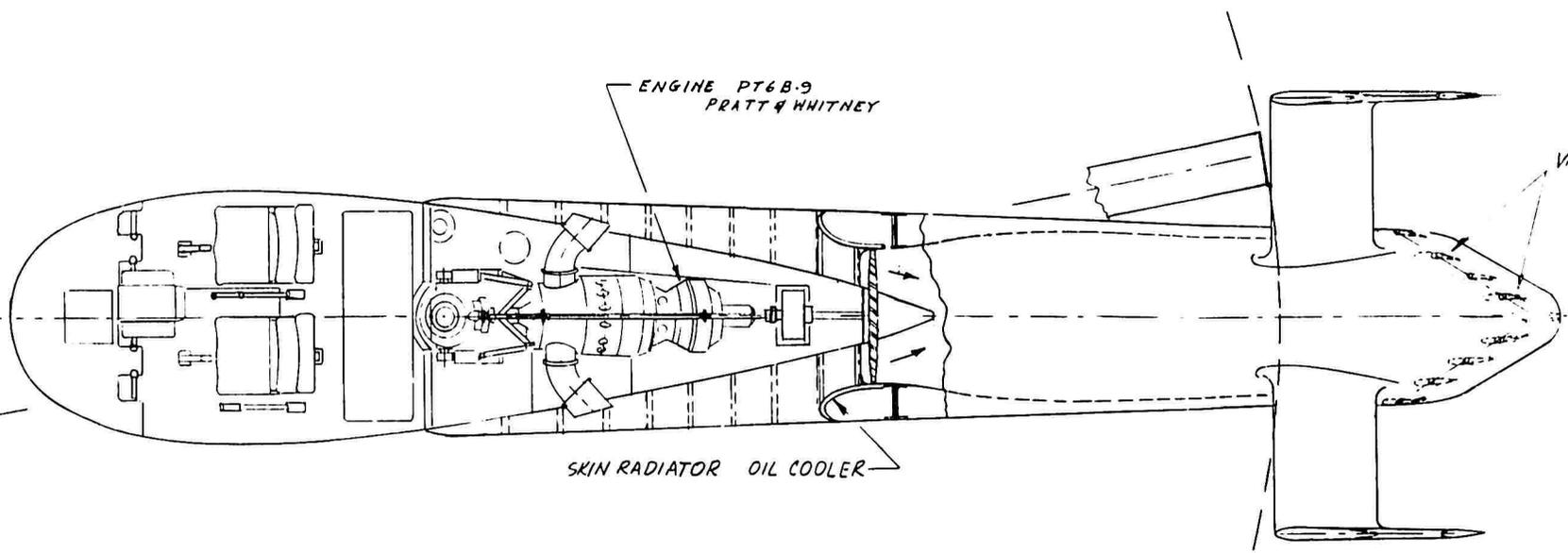


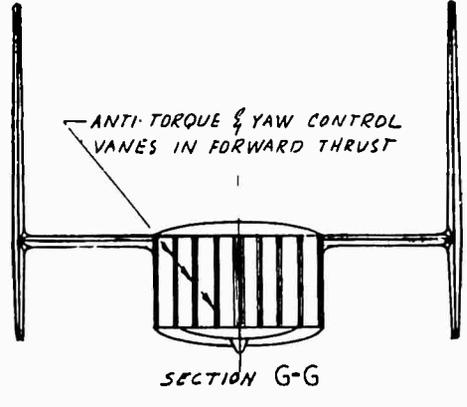
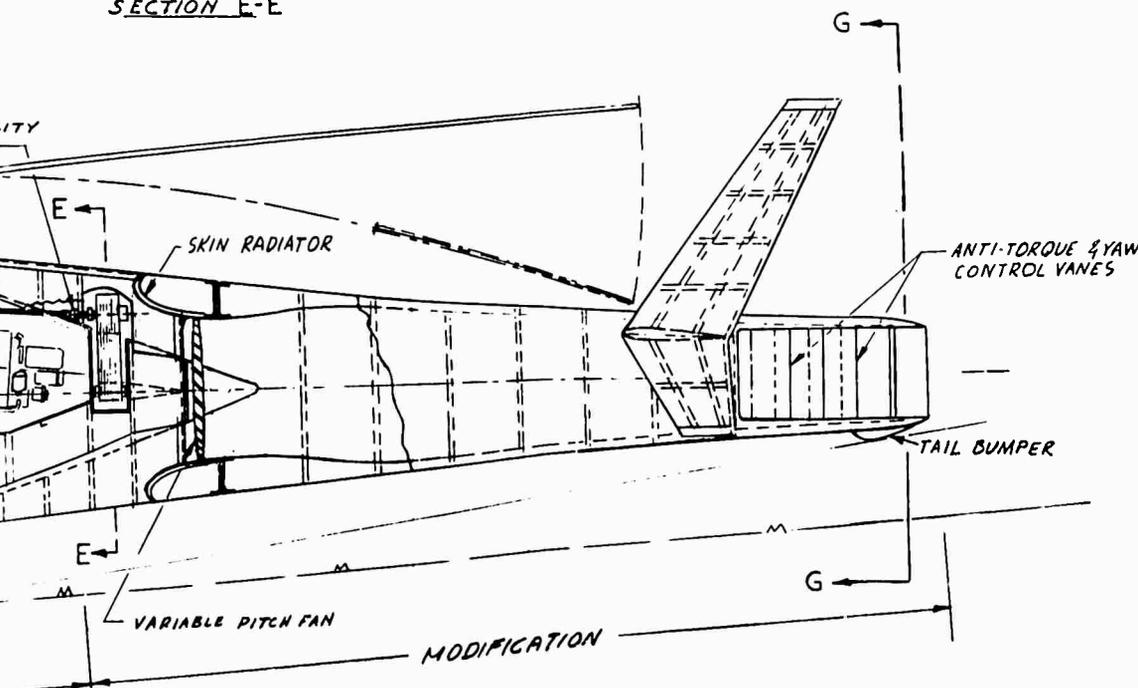
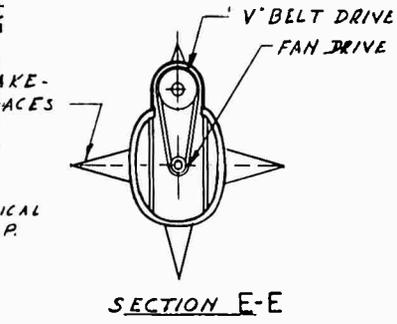
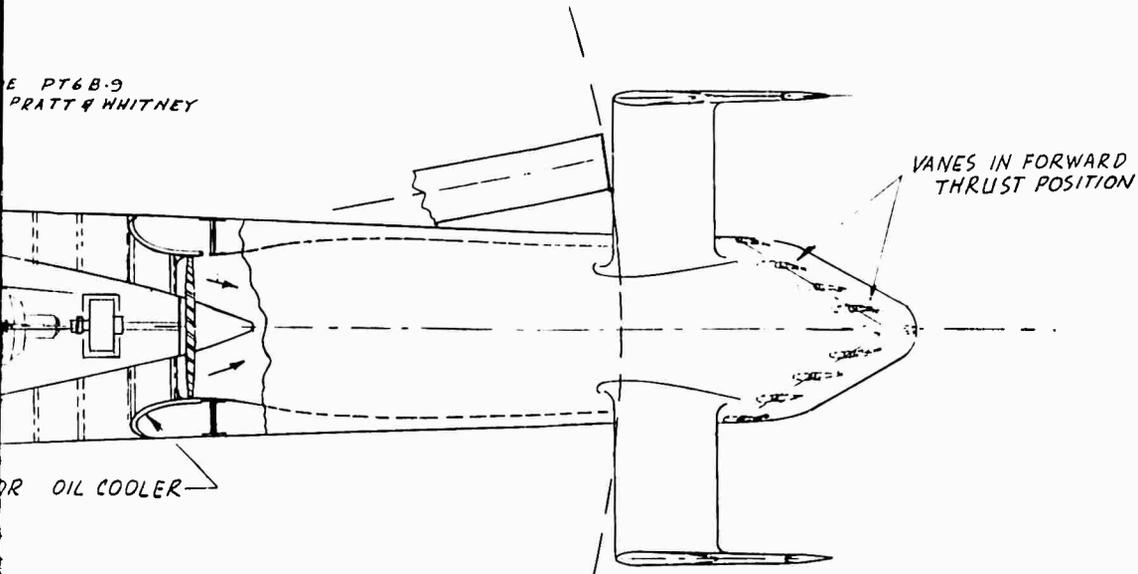
Figure 4. Inboard Profile - Internal Fan Concept.

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25a

E PT6B-9
PRATT & WHITNEY



25h

5a

propulsion. The variable-geometry dual-purpose exit shown in Figure 5 permitted the use of a large cross section in the aft fuselage without an appreciable drag penalty. Actually, a drag reduction resulted from a more level flight attitude with auxiliary forward flight propulsion. This large duct cross section and exit area also reduced duct losses and efflux velocity. Anti-torque power was thus reduced below that required by a 30-inch fan-in-fin. The internal installation of the fan reduces hazards to personnel to nearly zero and minimizes vulnerability to terrain-contact damage. Forward location of the fan results in maximum drive system simplicity with attendant gains in maintainability and reliability.

The system operates as follows: vanes are normally in the open forward-flight position and fan blades are at minimum pitch. In hovering flight, right- or left-rudder pedal displacement initiates a closing of the left or right set of vanes, respectively, and a proportional increase in fan blade angle. Keeping the fan blades at low pitch during small rudder pedal displacements prevents a large power drain from the main rotor system during critical power-off autorotation descents. As forward flight increases, the pilot selects the amount of forward flight propulsion thrust by increasing the fan blade pitch independently of rudder pedal displacement. Automatically and simultaneously, the degree of rotation of both sets of nozzle vanes is varied inversely proportional to forward thrust demand. This yields a smooth and continuous variation of yaw control power during transition from hover to forward flight with auxiliary propulsion.* Three optional fan designs are contemplated. The most economical choice would be an off-the-shelf fan from a SUD 341 helicopter. Figures 6 and 7 show two other fan designs sized to the requirement of this study. A third choice would be a fan furnished by Dowty Rotol who now have a variable-pitch fan design under test.

Special attention was paid to directional stability characteristics. The reduced stability experienced by many helicopters at low angles of sideslip has been identified as being caused by the fin and tail rotor being in a low energy turbulent wake behind the main rotor hub and pylon, rather than by a tail rotor load reversal. The twin fins shown in Figures 3 and 4 would be clear of this region of poor airflow, and would have the further advantage of maintaining good stability at high angles of attack in steep autorotation descents.

An inherent advantage of this configuration is the space available for a generous length of diffuser downstream of the compressor (fan). In the fan-in-fin configuration, the duct length is limited by frontal area and drag considerations, precluding any possibility of energy recovery through a diffusing tail pipe. The fan-in-fin diameter is therefore chosen to favor minimum induced power, compromising the optimum detail design of the fan itself. On the other hand, for the internal fan arrangement, since the momentum energy is governed by the exit area rather than fan diameter, the optimum (smallest, lightest) fan can be selected. This also permits consideration of a high-pressure-ratio supersonic fan as currently employed in modern turbofan engines. It further permits the use of various sizes of off-the-shelf fans with minimum performance penalty. An additional

* It is recognized that design of the control system must be preceded by a thorough analysis of control sequencing for the fan pitch and deflector vane angles to eliminate nonlinearities and dead-band.

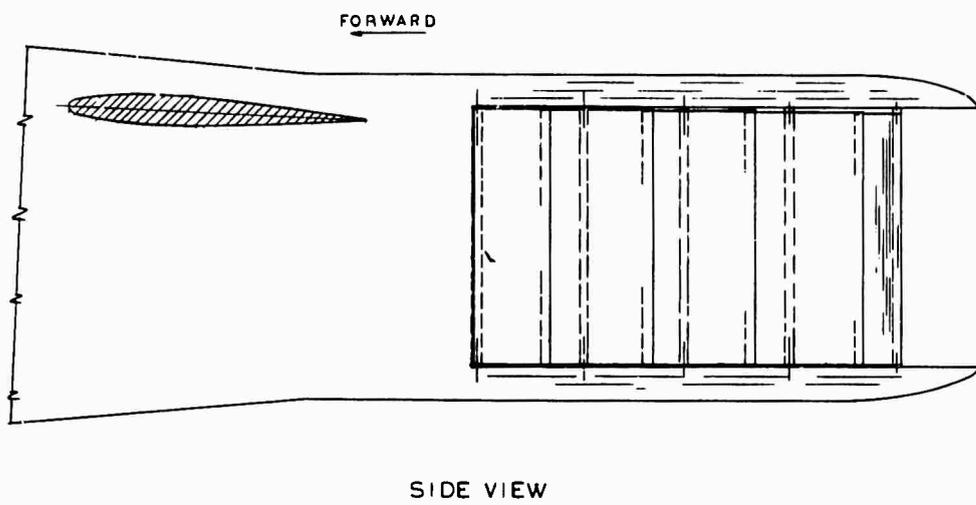
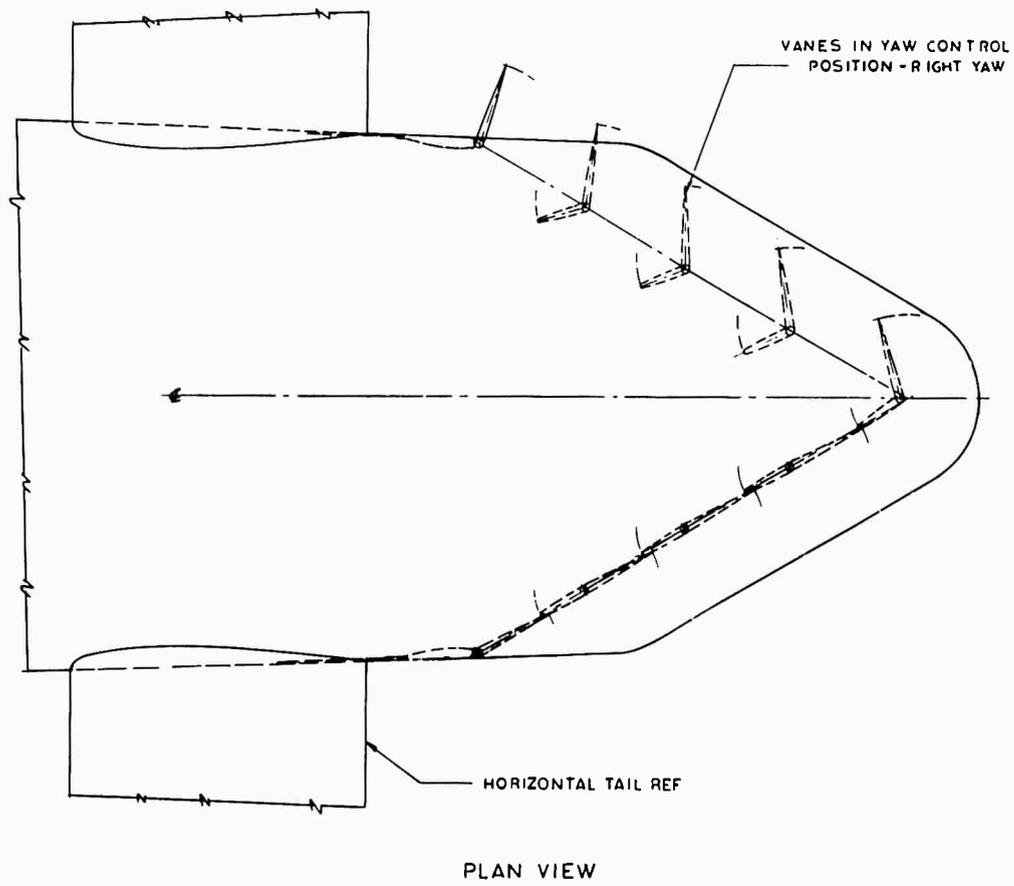
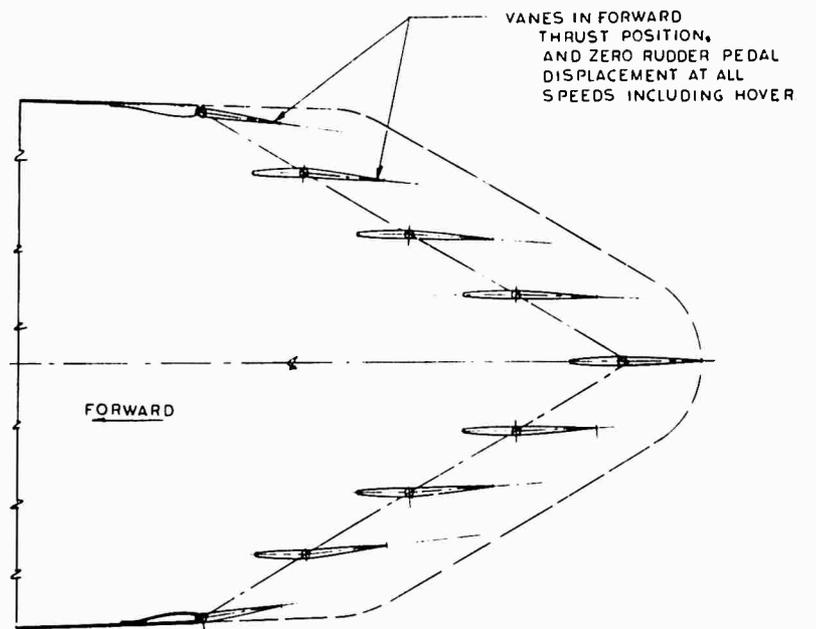
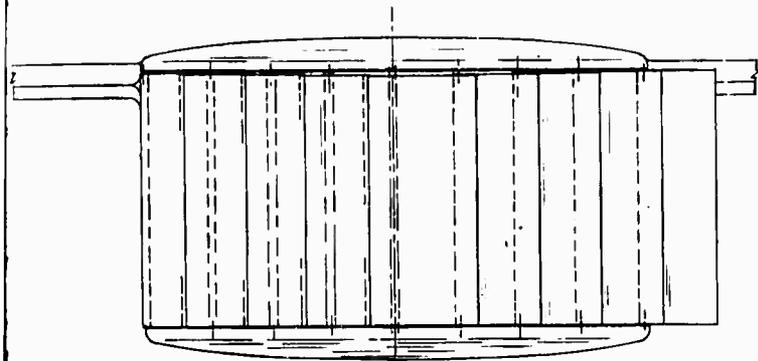


Figure 5. Variable-Geometry Nozzle.

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VANES
t 1/2



REAR VIEW

29a

VANES IN FORWARD
THRUST POSITION,
AND ZERO RUDDER PEDAL
DISPLACEMENT AT ALL
SPEEDS INCLUDING HOVER

VANES IN CLOSED
POSITION

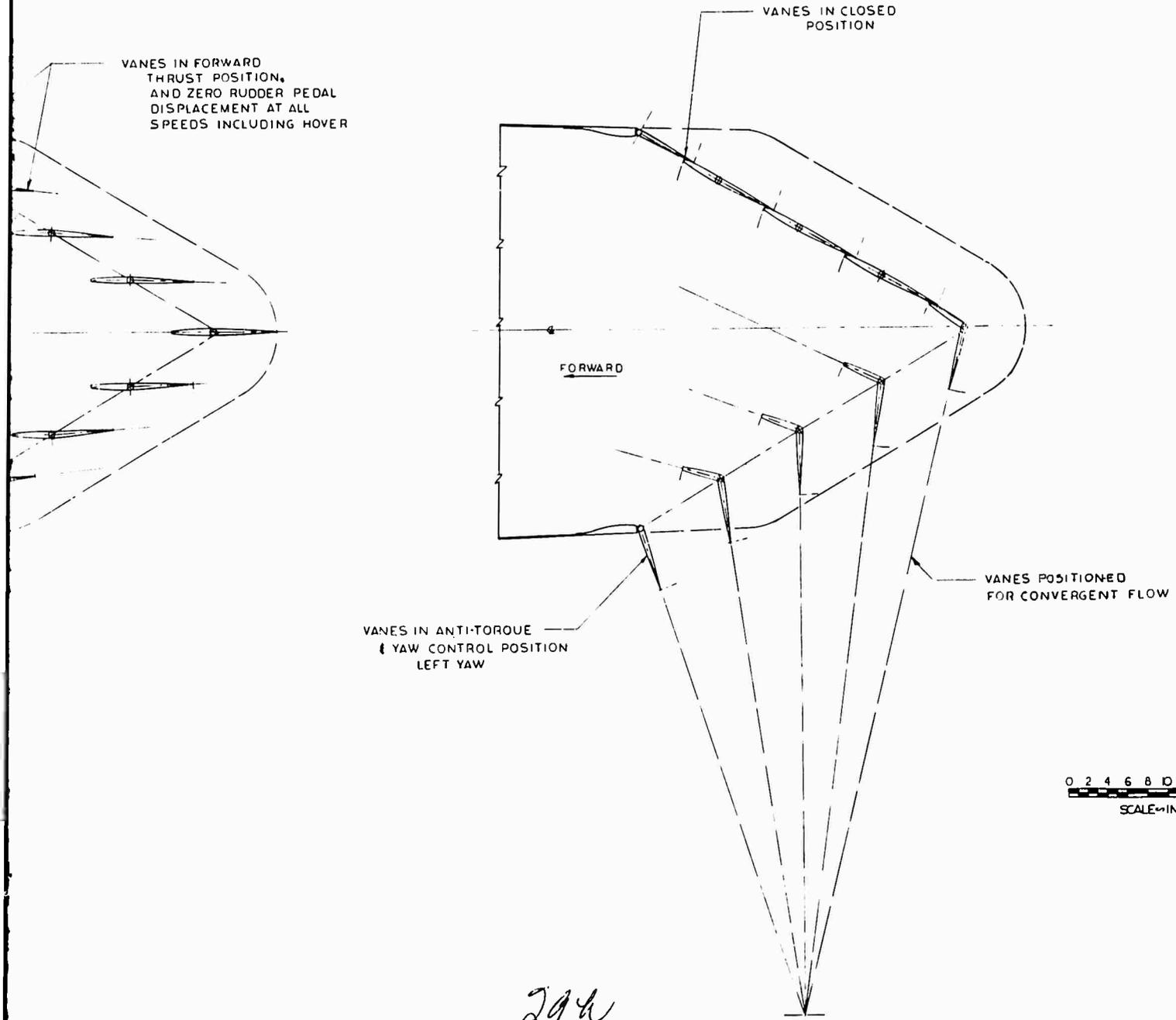
FORWARD

VANES POSITIONED
FOR CONVERGENT FLOW

VANES IN ANTI-TORQUE
YAW CONTROL POSITION
LEFT YAW

0 2 4 6 8 10 12 14 16 18 20
SCALE IN INCHES

294



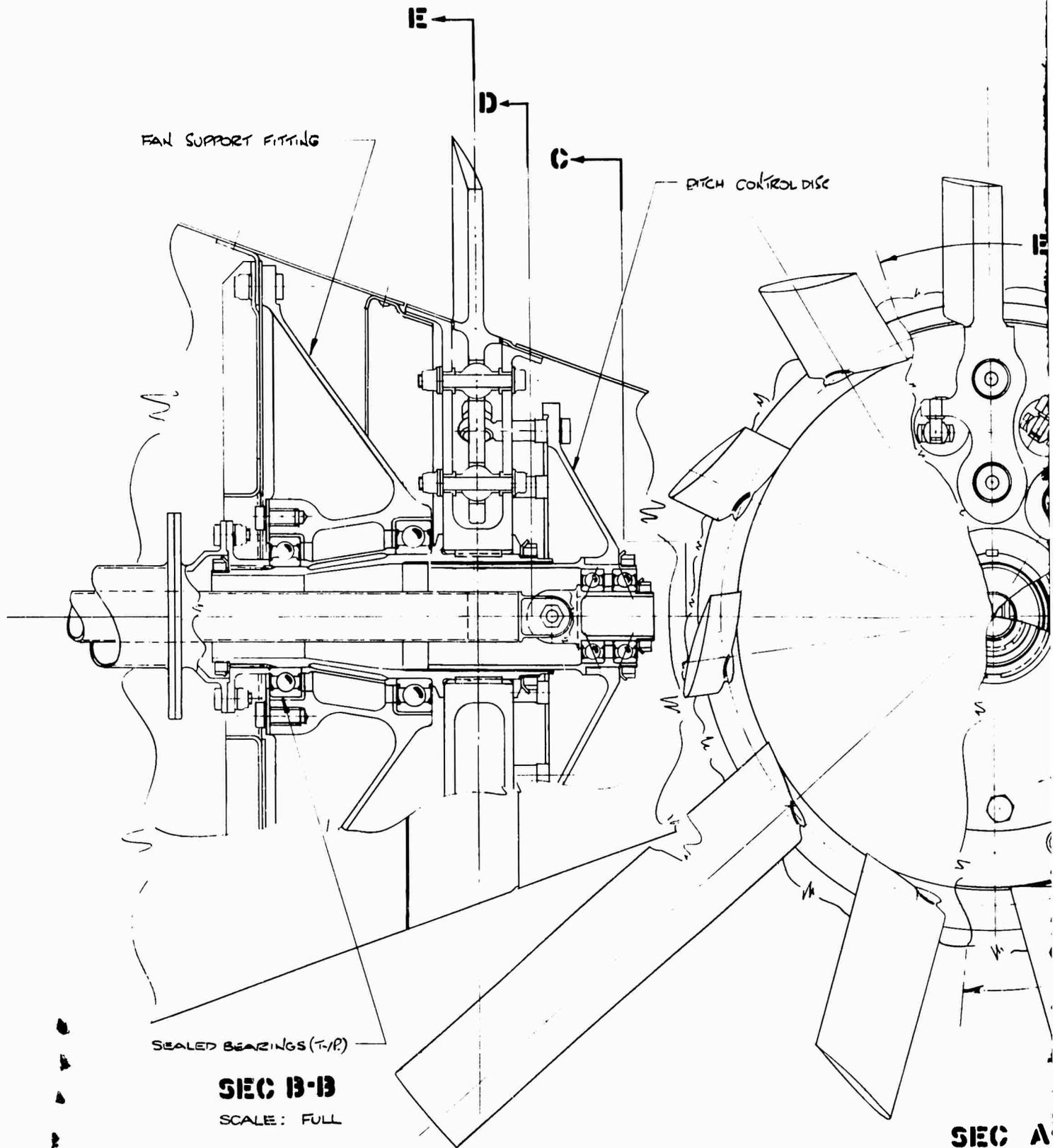
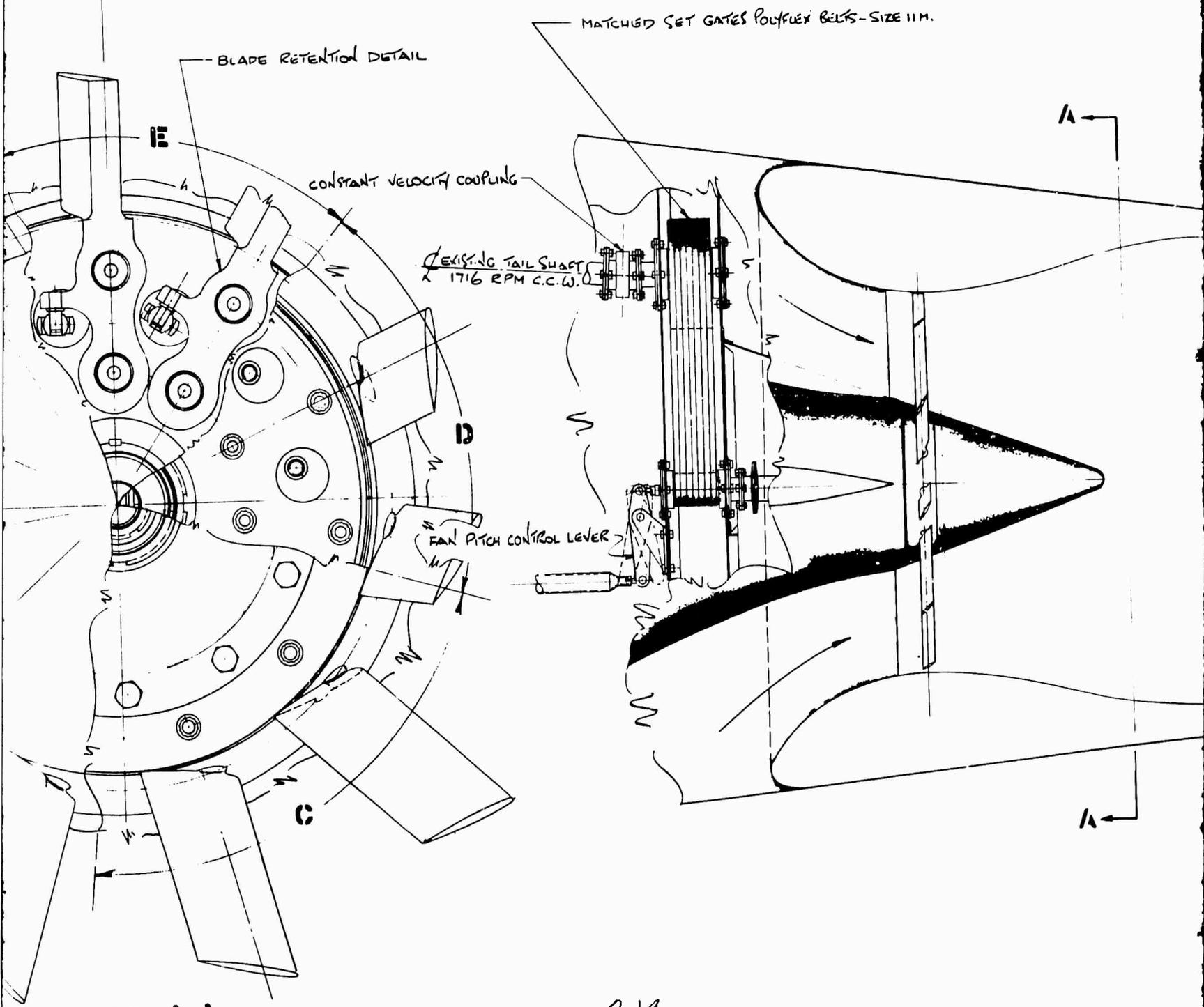
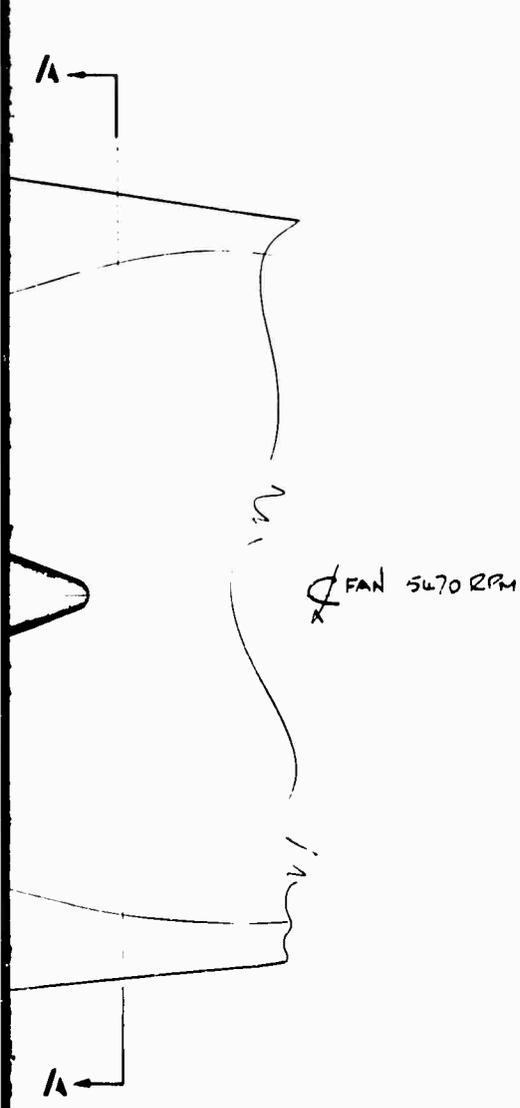


Figure 6. Variable-Pitch Internal Fan.

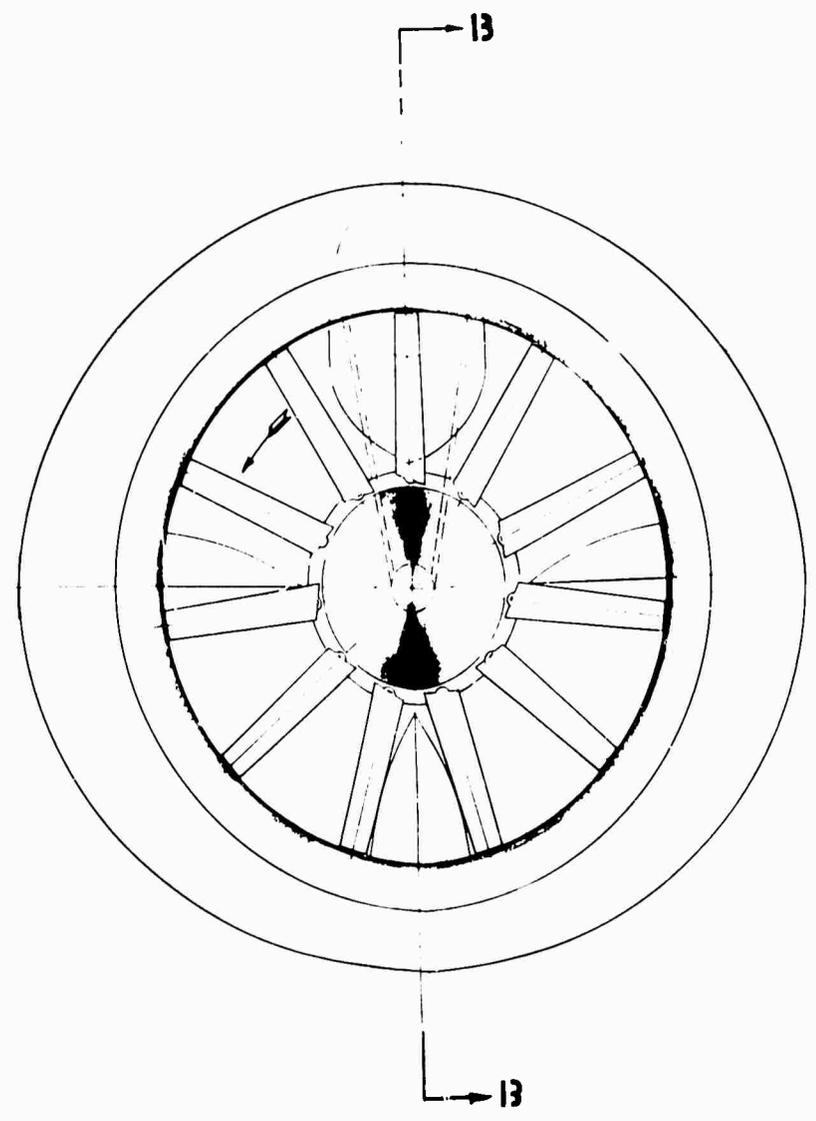


SEC A-A SCALE: FULL

31a

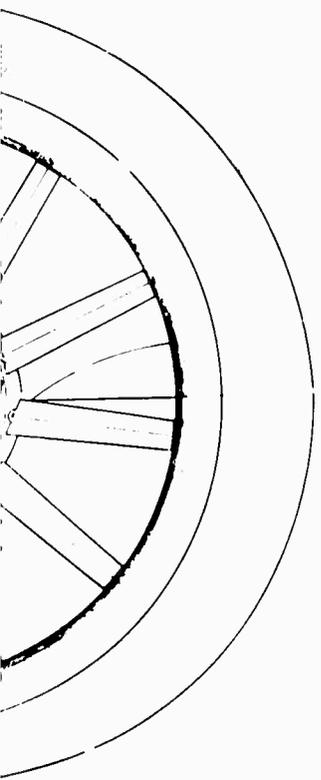


FAN 5470 RPM

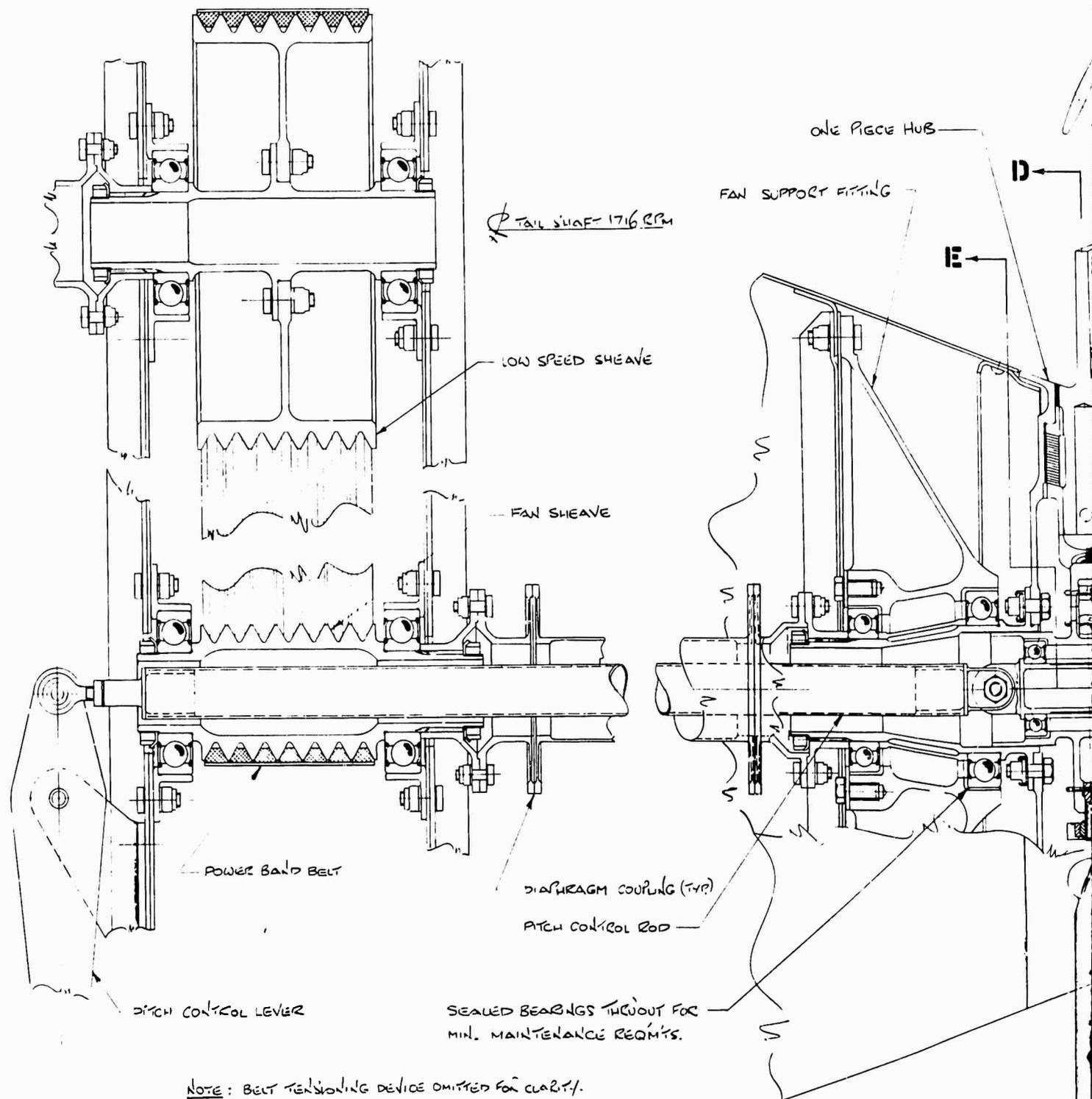


FULL SEC A-A

31h



31e



NOTE: BELT TENSIONING DEVICE OMITTED FOR CLARITY.

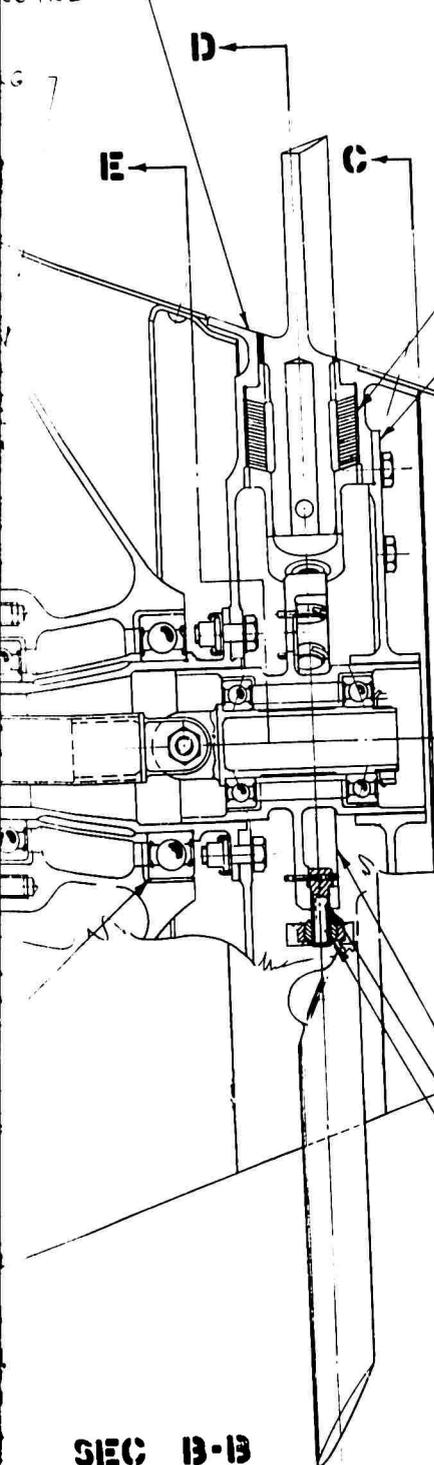
STEP-UP BELT DRIVE
SCALE: FULL

Figure 7. Advanced Variable-Pitch Internal Fan.

SEC B-B
SCALE: FULL

ICE HUB

7

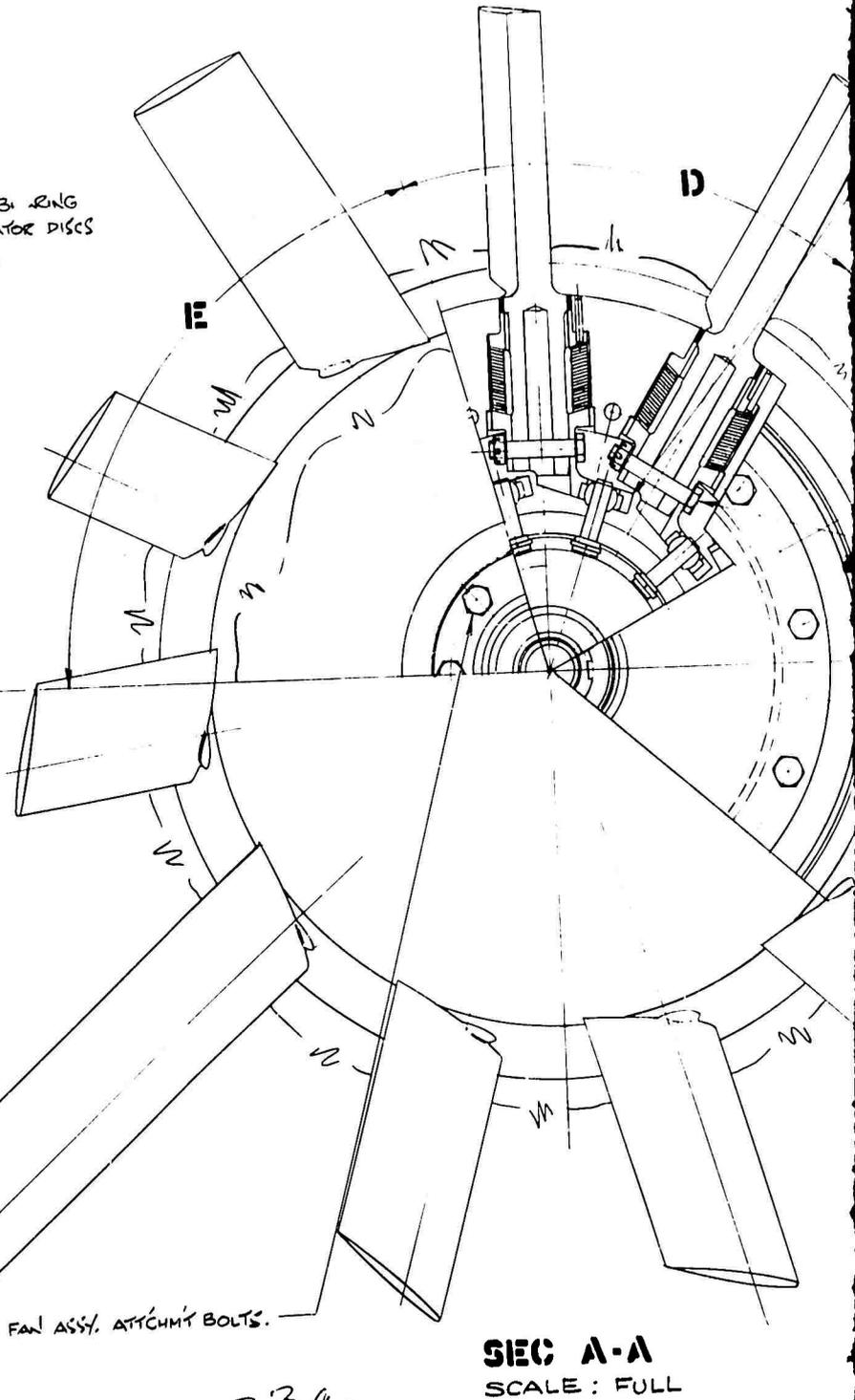


ELASTOMER BLADE RETENTION BAND
 PITCH RANGE: $\pm 30^\circ$. SEPARATOR DISCS
 DISHED FOR COLUMN STABILITY.
 CLOSURE PLATE

FAN 5470 RPM

FAN SPINNER
 PITCH CONTROL DISC
 PITCH CONTROL PIN (TYP)
 SPHER. BEARING
 STAKED TO PITCH ARM
 (TYP)

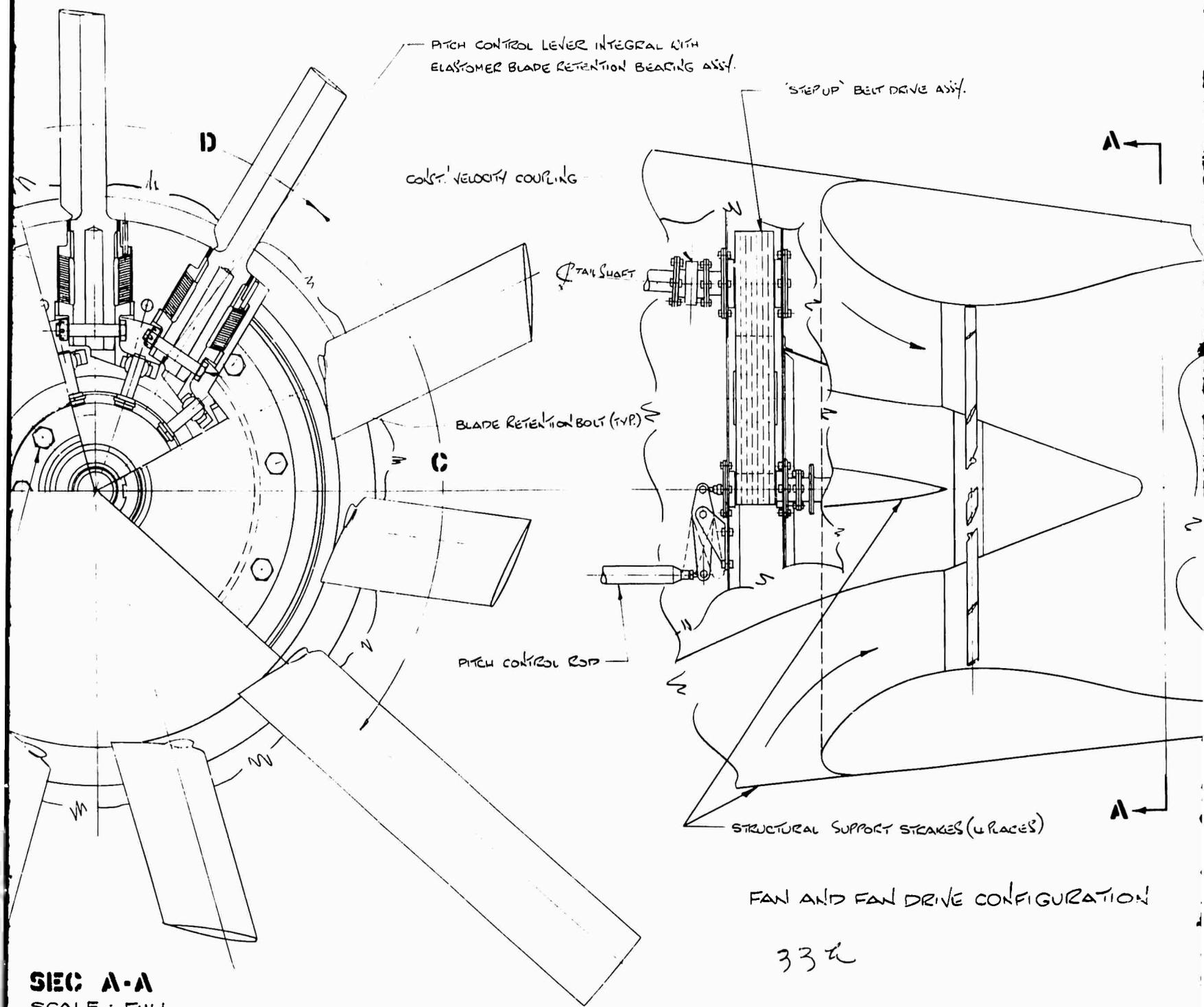
SEC B-B
 SCALE: FULL



FAN ASSY. ATTACHMT BOLTS.

33a

SEC A-A
 SCALE: FULL



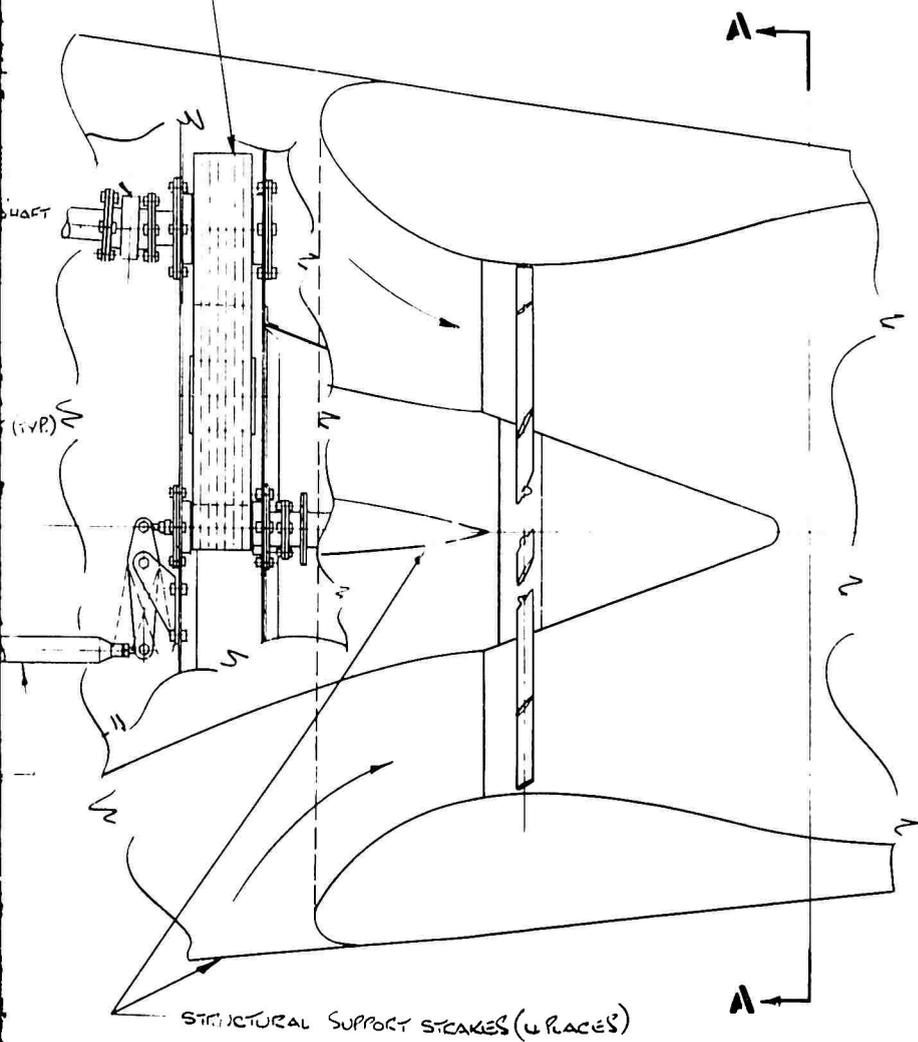
SEC A-A
SCALE: FULL

FAN AND FAN DRIVE CONFIGURATION

332

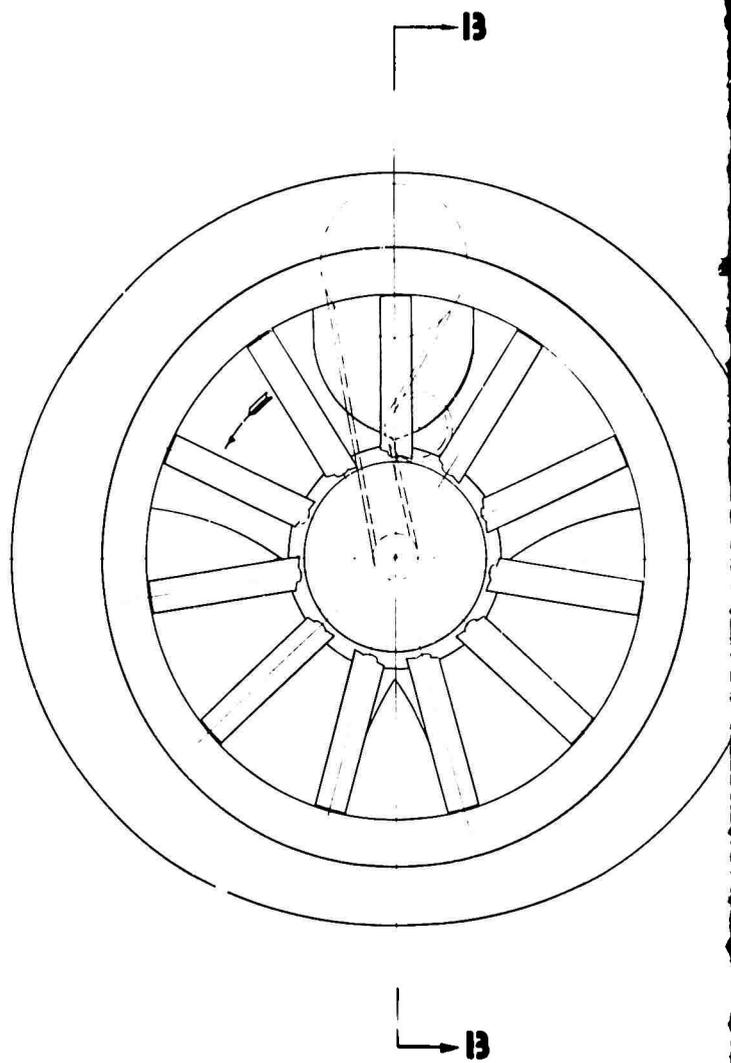
INTEGRAL WITH
MOUNTING BEARING ASSY

'STEP UP' BELT DRIVE ASSY.



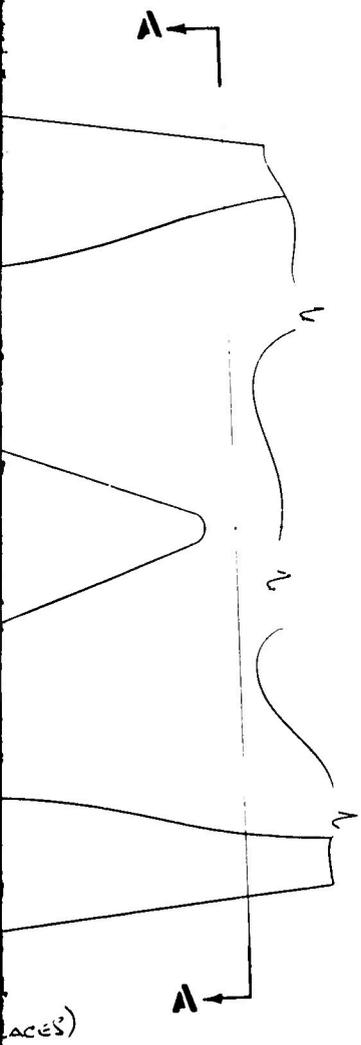
FAN AND FAN DRIVE CONFIGURATION

33c

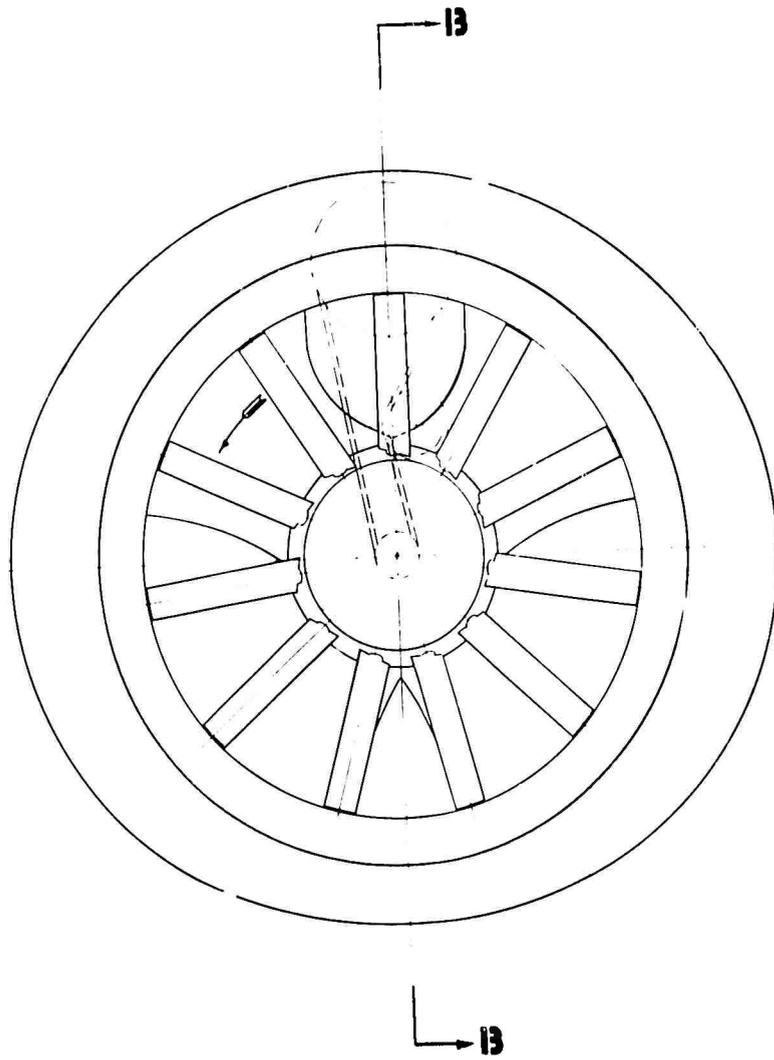


SEC A-A

33c



CONFIGURATION



SEC A-A

33e.

MAIN ROTOR

DIAMETER 35. FT.-0 IN.
CHORD 13.5 IN.
DISC AREA 962. SQ.FT.
TIP SPEED-NORMAL-650.FT. SEC.

HORIZONTAL TAIL

AREA 8.5 SQ. FT.

VERTICAL TAIL

AREA 16 SQ.FT.

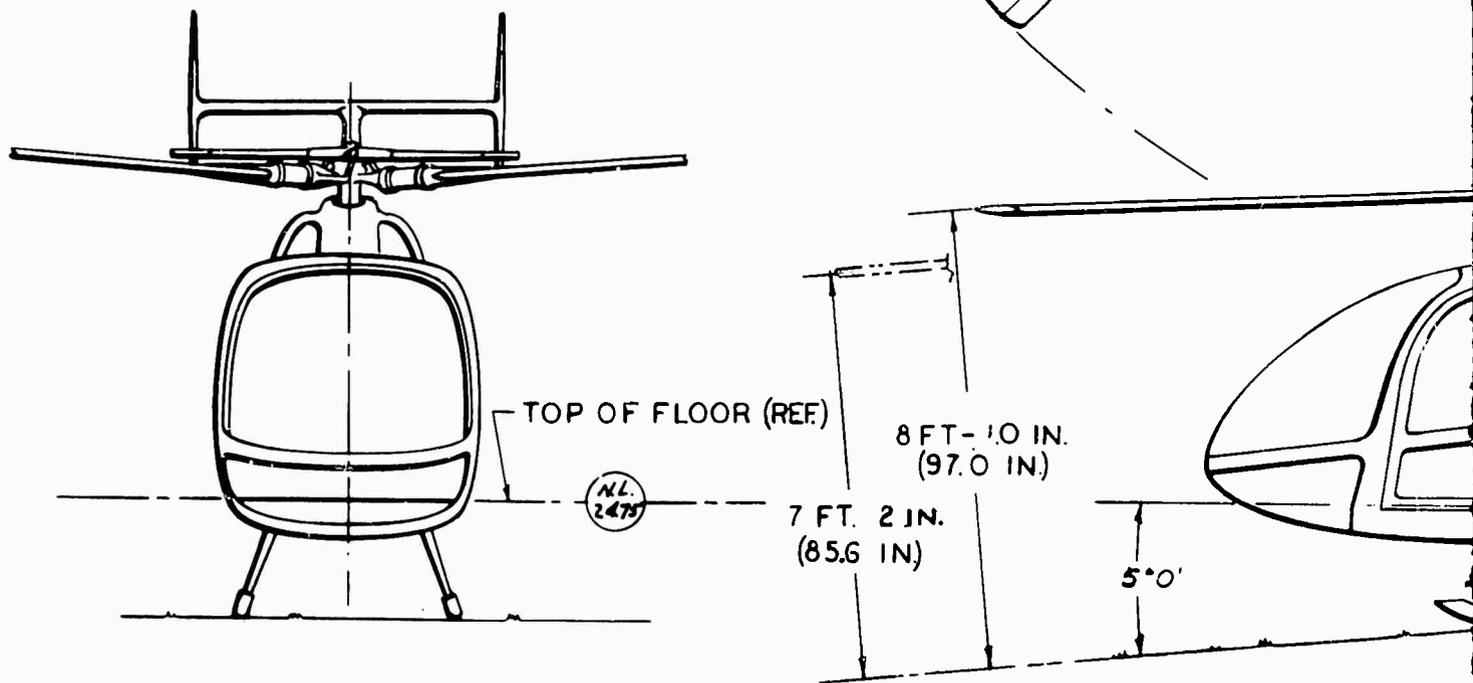
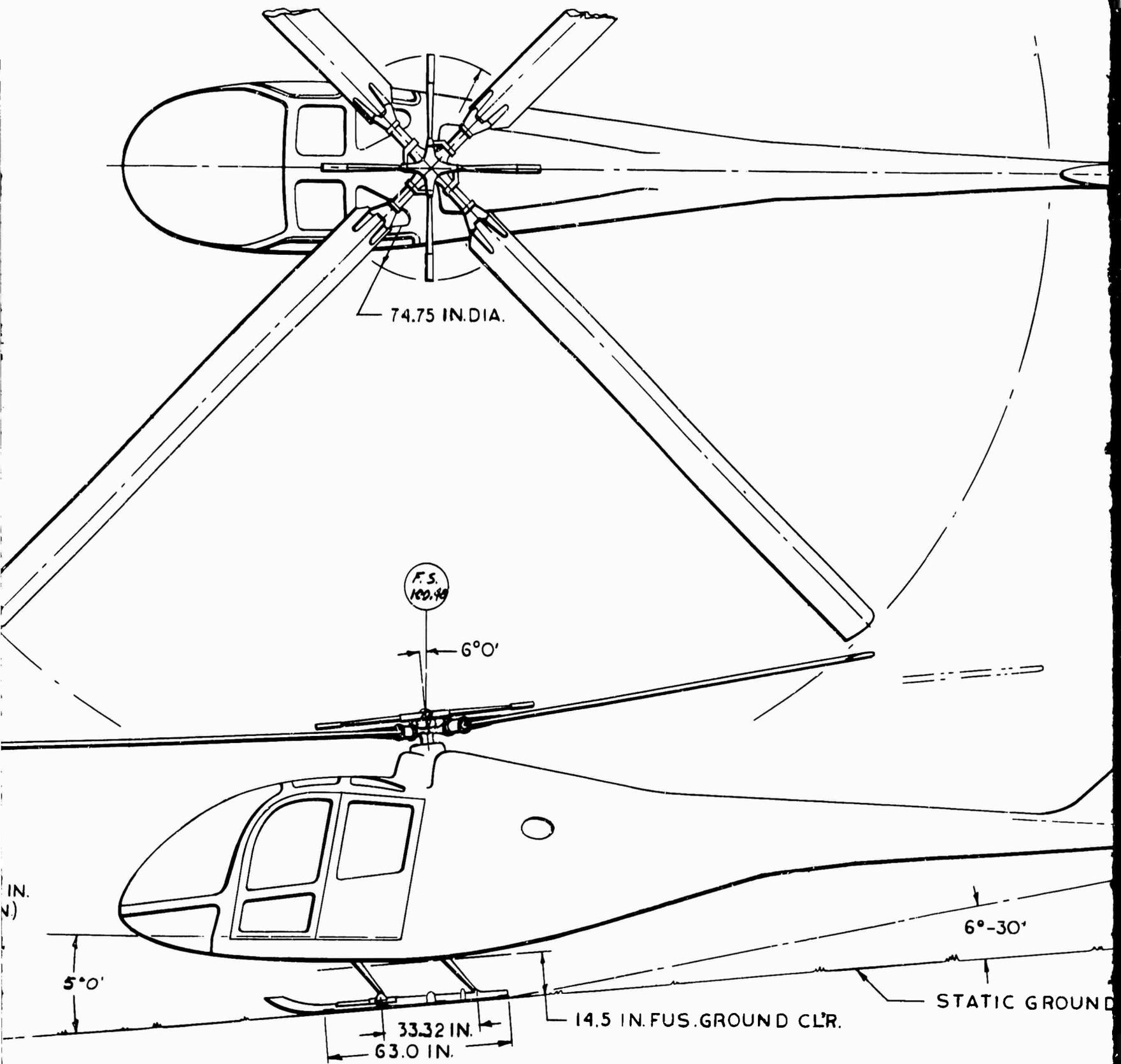
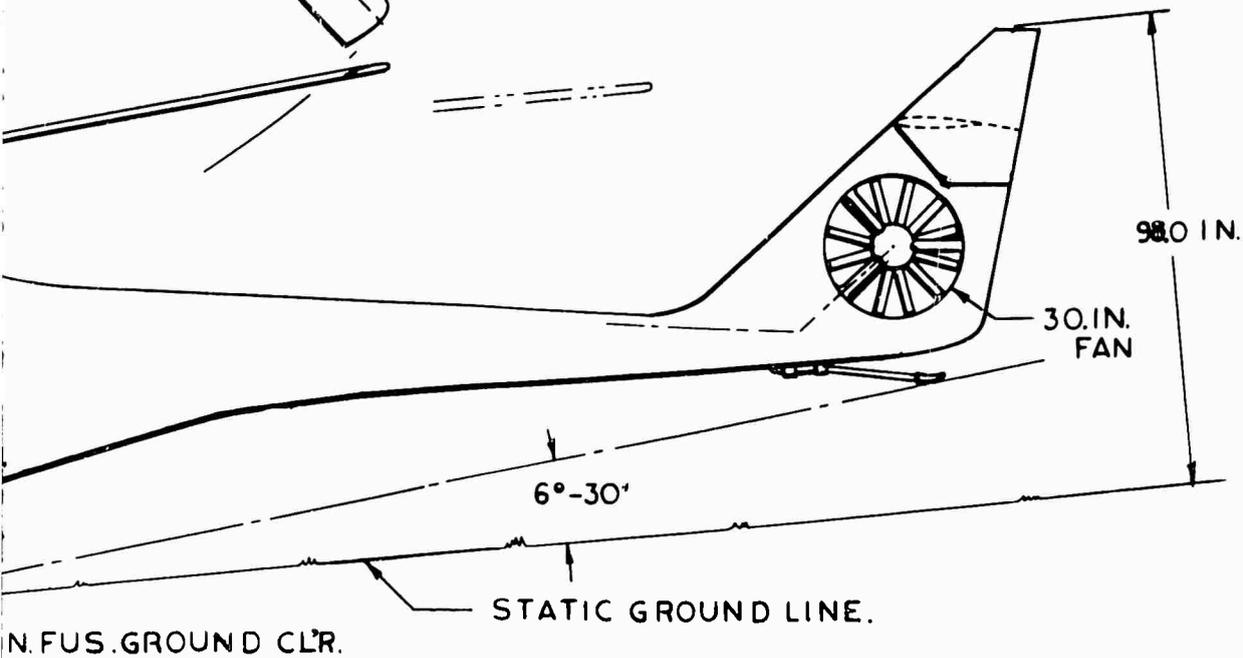
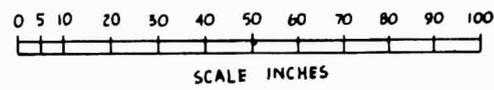
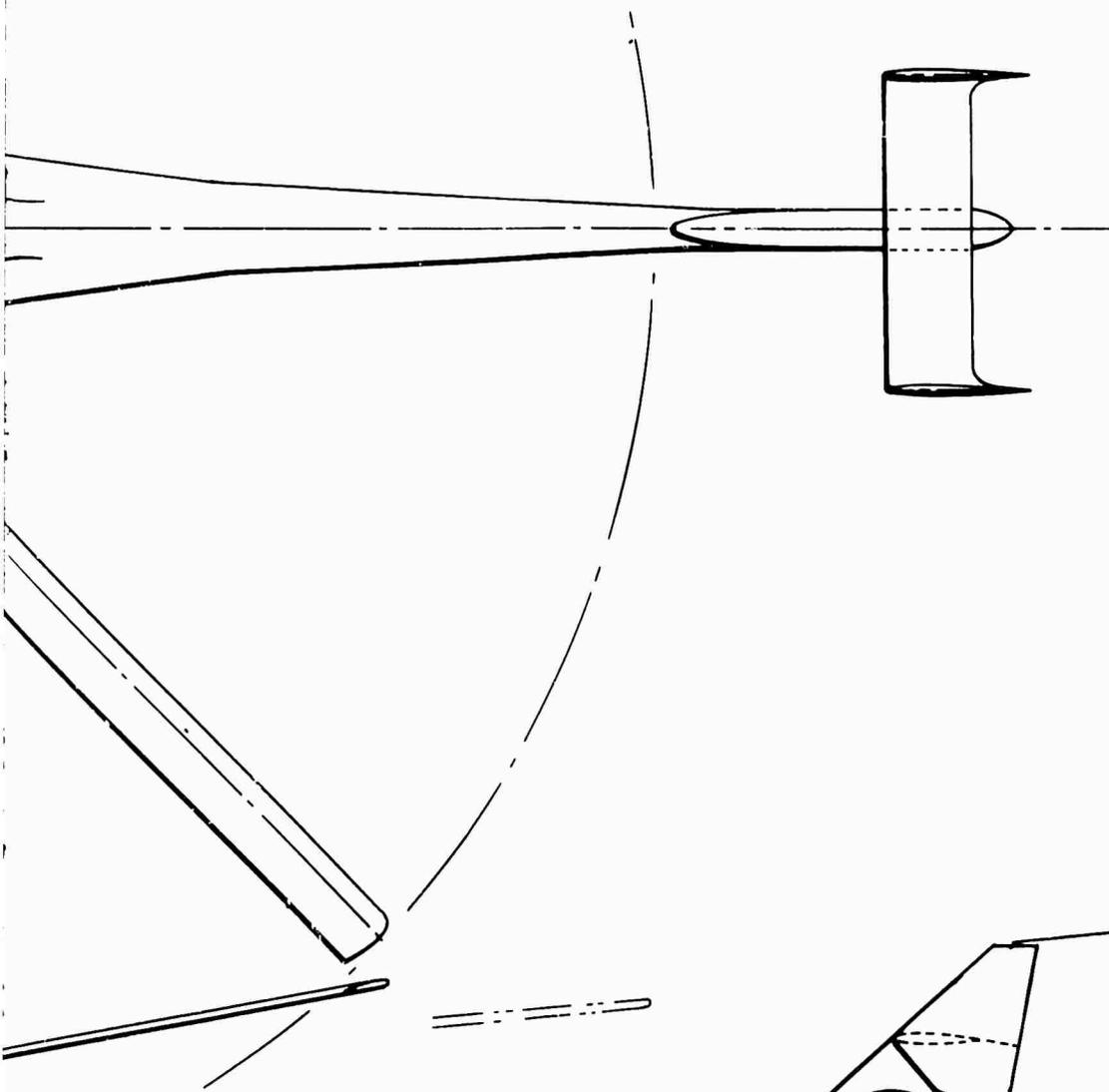


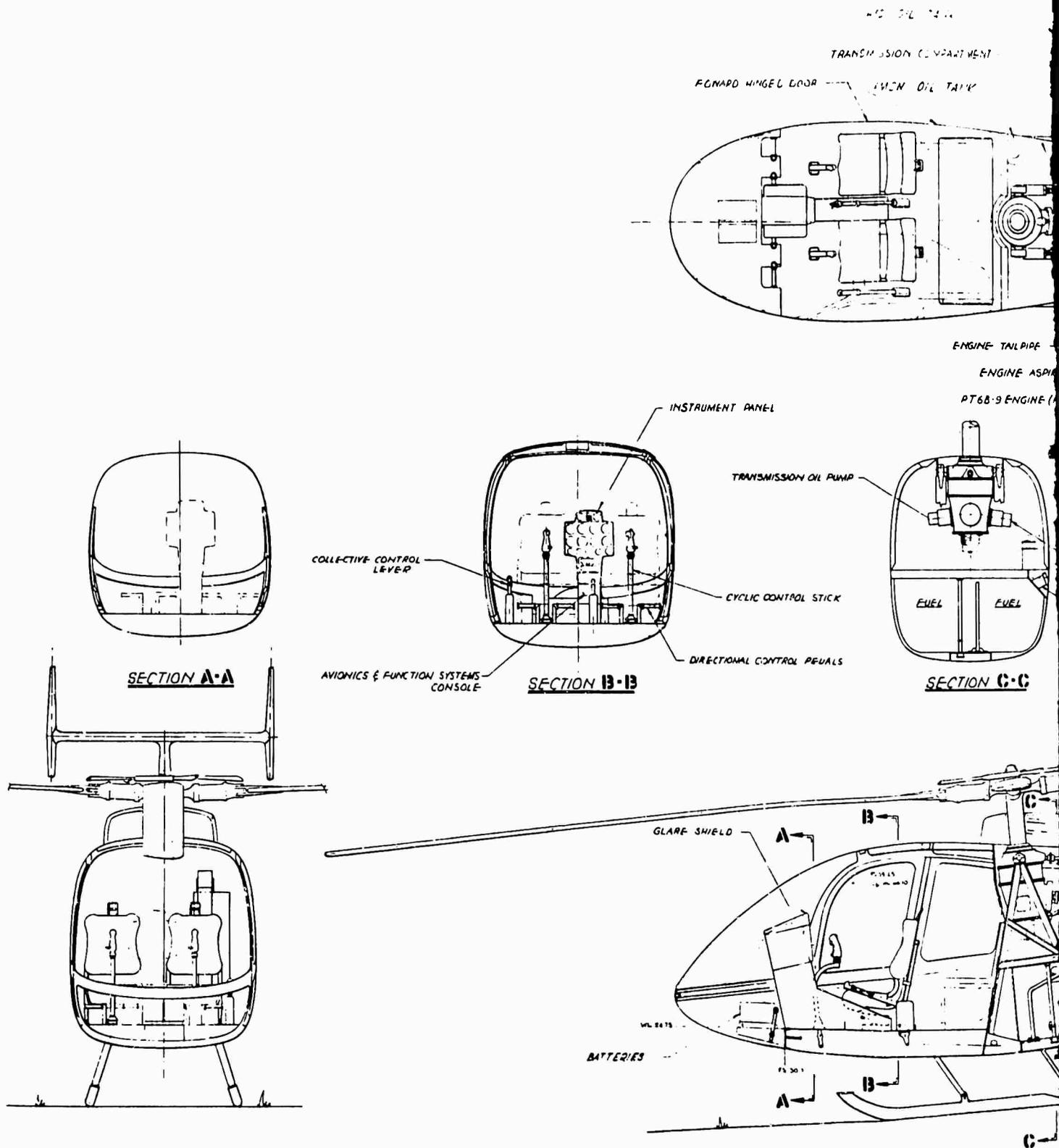
Figure 8. General Arrangement - 30-Inch Fan-in-Fin Concept.



35a



352



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NO OIL TANK

TRANSMISSION COMPARTMENT

MAIN OIL TANK

ENGINE EXHAUST COMPARTMENT

INDUCTION PLENUM & ACCESSORY COMPARTMENT

BLOWER INLET DUCT

OIL COOLER BLOWER

OIL COOLER

COOLER AIR OUTLET DUCT

STARTER GENERATOR

ENGINE TAILPIPE

ENGINE ASPIRATOR

PT68-9 ENGINE (PRATT & WHITNEY)

ENGINE AIR INLET

OIL FILLER & DIP STICK

STARTER GENERATOR

OIL COOLER

REAR ENGINE MOUNT

FUEL STRAINER

COMMON DRAIN MANIFOLD

ELECTRICAL EQUIP

FUEL PUMP

FIRE SHIELD

AVIONICS

HYDRAULIC PUMP

YMSM OIL TANK

FUEL TANK FILLER

SECTION D-D

SECTION E-E

SECTION F-F

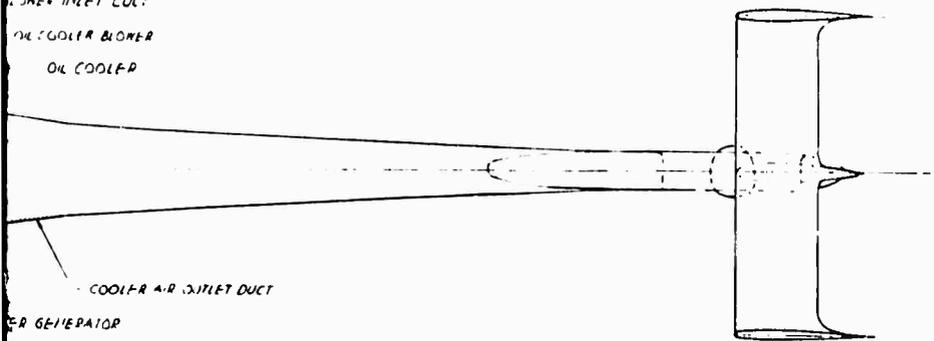
SECTION C-C

INTERMEDIATE GEAR BOX

TITANIUM FIREWALL

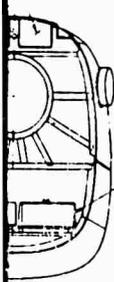
37a

COMPARTMENT
 FUEL PLENUM & ACCESSORY COMPARTMENT
 BLOWER INLET DUCT
 OIL COOLER BLOWER
 OIL COOLER



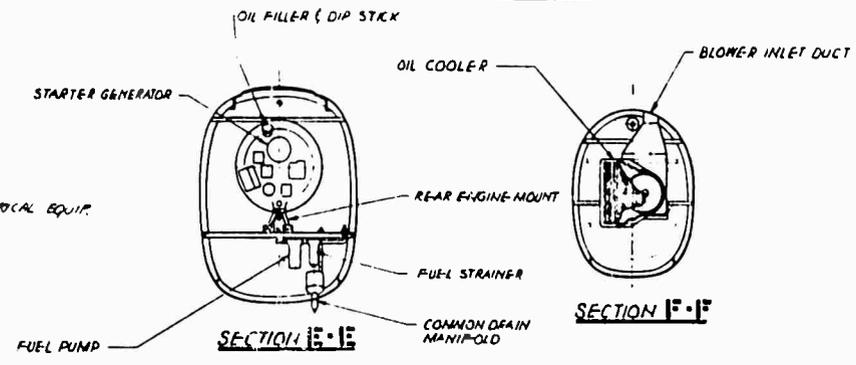
COOLER AIR INLET DUCT

STARTER GENERATOR
 REAR ENGINE AIR INLET



ELECTRICAL EQUIP.

SECTION D-D



STARTER GENERATOR

OIL FILLER (DIP STICK)

OIL COOLER

BLOWER INLET DUCT

REAR ENGINE MOUNT

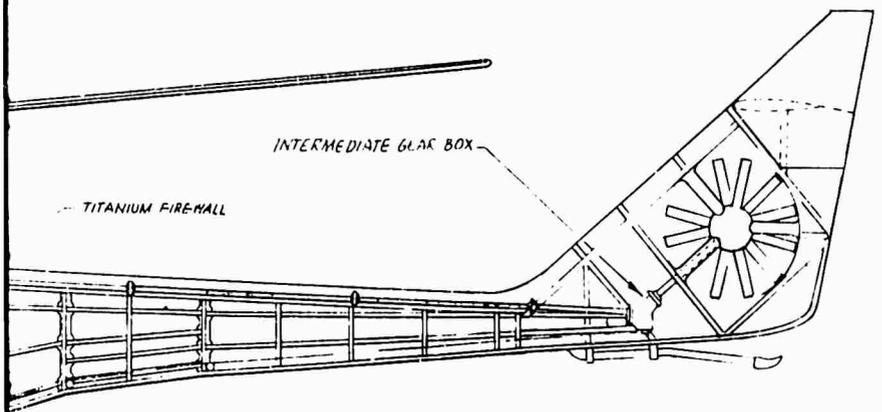
FUEL STRAINER

SECTION F-F

FUEL PUMP

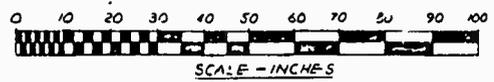
SECTION E-E

COMMON DRAIN MANIFOLD



INTERMEDIATE GLAR BOX

TITANIUM FIREWALL



SCALE - INCHES

37h

7a

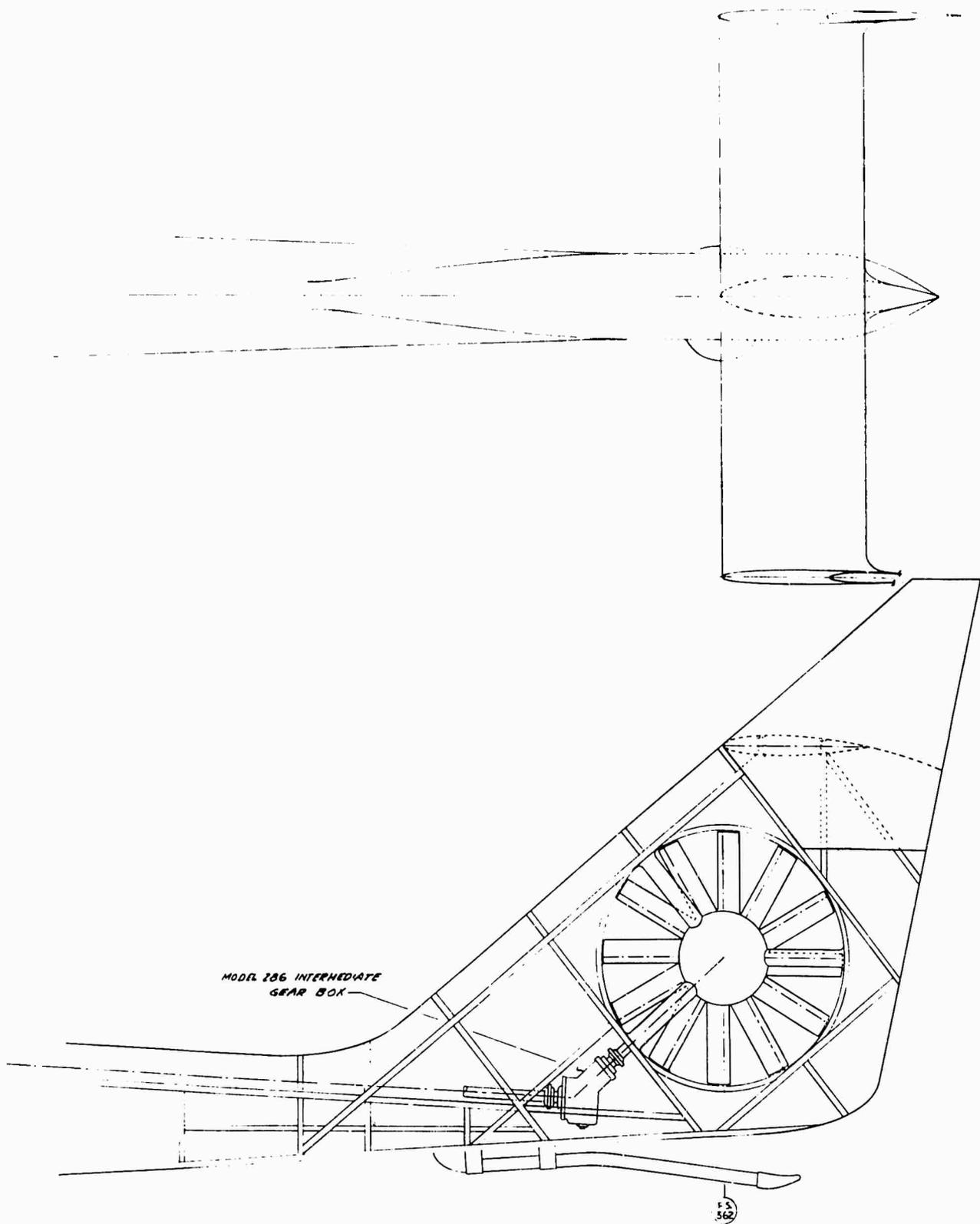
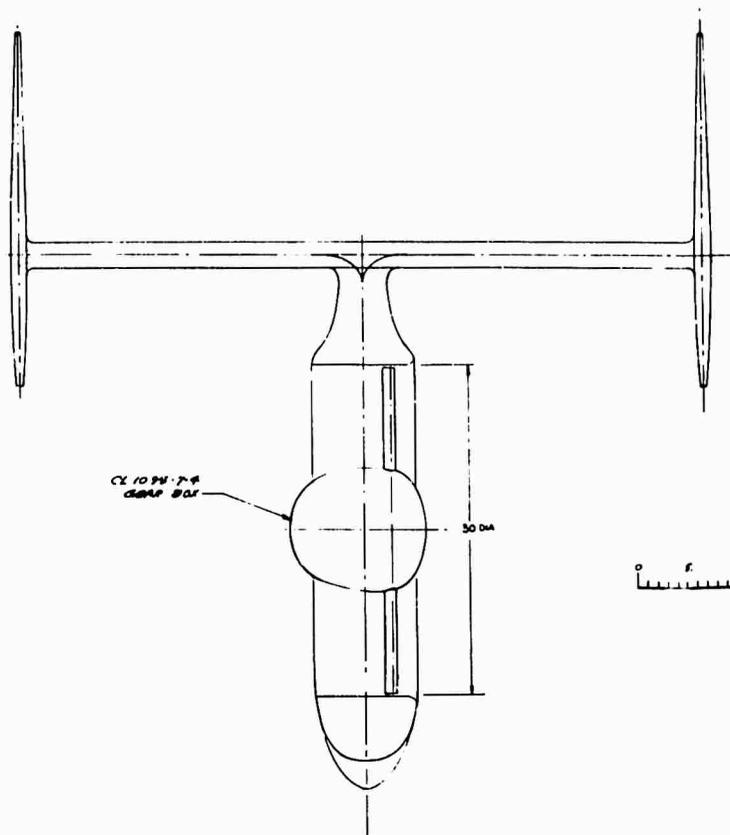


Figure 10.. 30-Inch Fan-in-Fin Installation.

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39a

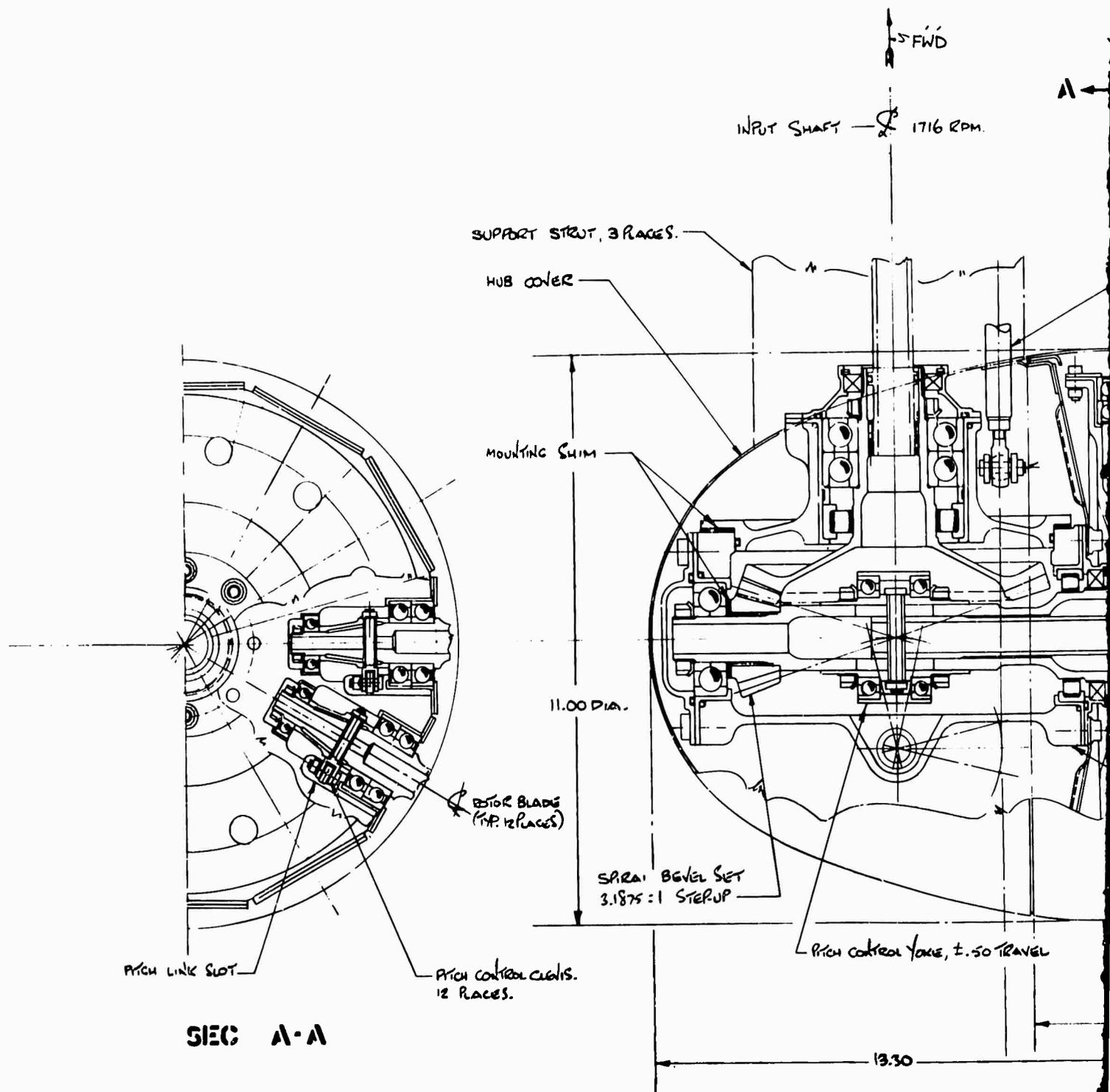
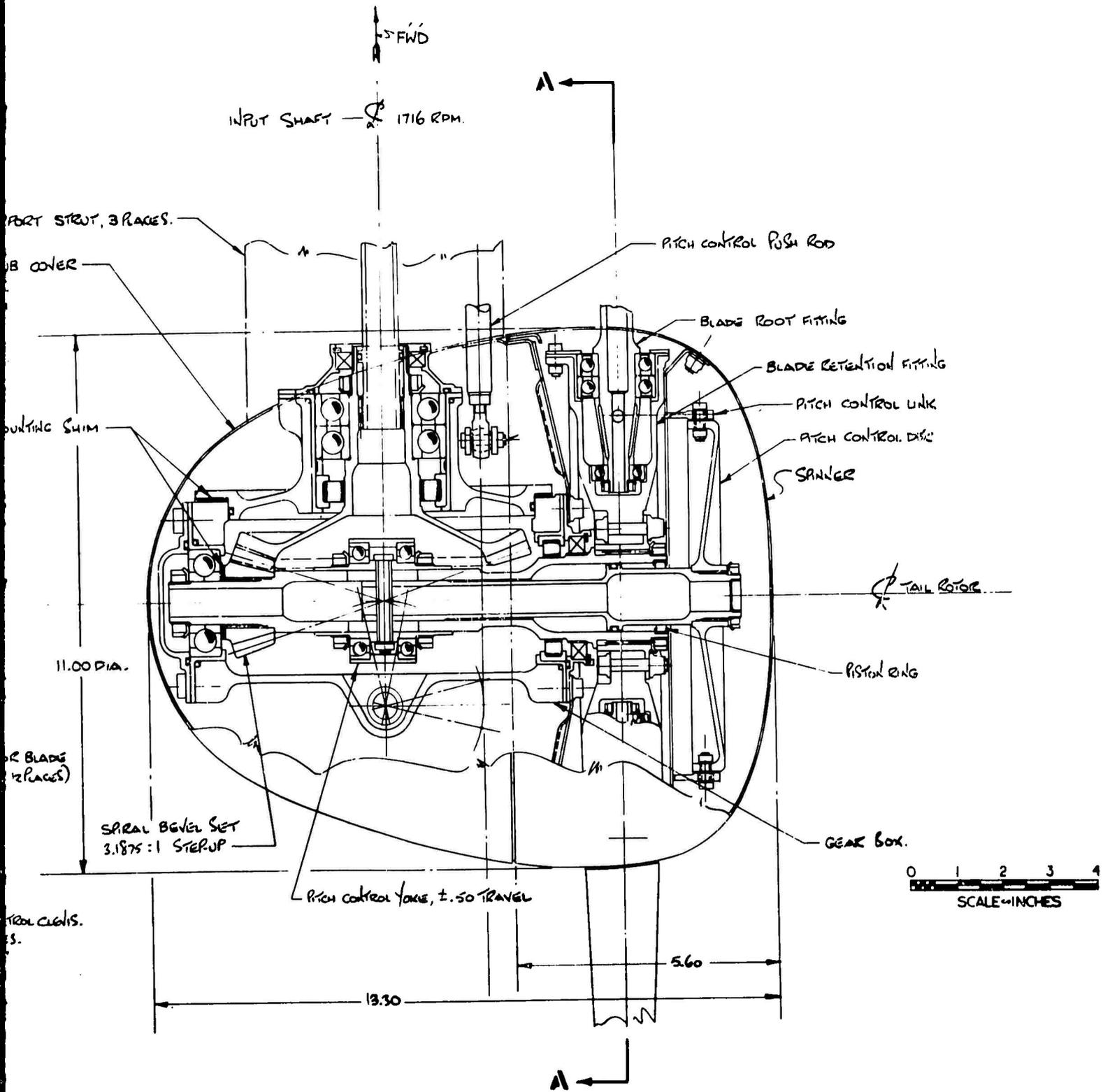


Figure 11. Fan-in-Fin Gearbox and Hub.

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PORT STRET, 3 PLACES.

HUB COVER

MOUNTING SUM

11.00 DIA.

OR BLADE (2 PLACES)

SPIRAL BEVEL SET
3.1875:1 STEP UP

REAR CHAS.
ES.

Carbox and Hub.

INPUT SHAFT — 1716 RPM.

5 FWD

PITCH CONTROL PUSH ROD

BLADE ROOT FITTING

BLADE RETENTION FITTING

PITCH CONTROL LINK

PITCH CONTROL DISC

SPANNER

TAIL ROTOR

PISTON RING

GEAR BOX.

Pitch control travel, ±.50 TRAVEL

0 1 2 3 4
SCALE IN INCHES

5.60

13.30

A19.

advantage of this concept is the fortunate matching of the airflow through the bellmouth inlet, and the heat rejection of the engine and transmissions. This suggests the use of a skin radiator to provide engine and transmission oil cooling without the need for a blower, an oil cooler, and associated ducting. The weight and power of the cooling blower is saved, and the heat transfer radiator is obtained at minimum weight.

A comparison of this concept, a conventional tail rotor design and the fan-in-fin concept was made based on the same gross weight and installed power margin. The engine power and propulsion system weights were increased over those of the tail rotor design as required by the new concepts. Weights were based on new designs rather than modifications. Results of the analysis show a 4.2% increase in power required to hover for the internal fan and a 5% increase for the fan-in-fin, with corresponding increases in propulsion weight and weight empty. However, weight-empty fractions are only slightly increased for both concepts over the conventional tail rotor. Specific range is substantially increased for the internal fan over the conventional tail rotor (4%) and is increased half as much (2%) for the fan-in-fin. As a result, the internal fan payload-range variation surpasses the conventional tail rotor for ranges greater than 140 miles. For the fan-in-fin, the curves cross at a range of 180 miles. (See Figure 34).

FAN-IN-FIN CONCEPT (30-INCH DIA)

Rating just below the internal fan concept, the fan-in-fin design presented herein is derived from and is very similar to the "Fenestron" of the French SUD 341. An application of this concept to the Model 286 is shown in Figures 8 and 9. The objectives of reduced hazard to ground personnel and ground-contact damage are substantially met, although not to the same degree as the internal fan. Nose and foreign object damage susceptibility are also somewhat less favorable than those of the internal fan. From a reliability and maintainability point of view, the more complex system of the fan-in-fin with two additional gearboxes is somewhat less attractive than the variable-geometry nozzle of the internal fan. (The belt drive shown for the internal fan is not inherent to the design and is only applicable to a retrofit modification.) The raised position of the fan as compared to the SUD 341, requiring an additional intermediate gearbox, provides additional clearance for a larger diameter, lower-disc-loading fan with improved efficiency and reduced power requirements. The fan design could be an off-the-shelf article or a special design as discussed in the internal fan section. One configuration of the gearbox and fan pitch control is shown in Figures 10 and 11. The weight of the fan-in-fin concept is quite comparable to the internal fan, but as mentioned previously, is somewhat less efficient powerwise due to the relatively short duct length limited by frontal area and drag considerations. As in the case of the internal fan, twin fins are provided for adequate directional stability at low angles of yaw and at high angles of attack in steep autorotational descents.

SUPPLEMENTARY STUDIES

In addition to the studies of the two selected concepts, other configurations were studied prior to, during, and after the final selections. These supplementary studies aided in making the tentative and final selections, and in checking the validity of the final selection. The degree of completeness of these studies varied considerably. A brief discussion of each follows.

Internal Fan with Forced Circulation

A substantial side force can be produced on a cylindrical body by inducing a circulation component to transverse airflow. Although limited to powered hovering or low-speed flight, a useful auxiliary anti-torque force augmentation can be obtained at minimum cost in power and complexity by inducing a forced flow circulation around the fuselage under the maximum velocity region of the main rotor downwash. An excellent application of this concept is with the internal fan configuration previously described. The configuration lends itself ideally to this augmentation, since the required source of compressed air and a relatively large cylindrical shape in the way of maximum rotor downwash are already available. A configuration showing the combination of these two concepts is illustrated in Figure 12. The forced circulation is obtained by blowing tangential air jets fed by the plenum duct between the fan and nozzle. These slots are normally closed, and open only under maximum control requirements when the increased pressure in the duct opens the spring-loaded slot lips. This prevents a power drain under critical power-off autorotation when control requirements are less severe. A further gain obtained by the forced circulation is the reduction or reversal of download on the aft fuselage due to rotor downwash. This results from the combination of two effects. First, the slots energize the boundary layer and tend to prevent flow separation in the lower surface of the fuselage. This reduces the high download (drag) characteristics of flow normal to a blunt unfaired cylindrical shape. The possibility of a net lift results from the inclination of the downwash produced by slipstream rotation. This inclination, corresponding to the helix angle of the slipstream, inclines the side force upward as shown in Figure 12, cross section F-F, giving a lift component.

28-Inch Fan-in-Fin

The 28 inch fan-in-fin anti-torque concept shown in Figures 13, 14, and 15 is a variation of the fan-in-fin configuration discussed previously. It follows closely the general arrangement of the SUD 341, except for the addition of twin vertical fins to provide adequate low-angle directional stability. Space limitations imposed by the straight-through drive shaft tend to limit the fan diameter and increase the disc loading. This is compensated by a gain in reliability and maintainability through the elimination of the intermediate gearbox. Hazards to ground personnel and vulnerability to terrain-contact damage, however, are not as favorable as with the 30-inch fan-in-fin configuration.

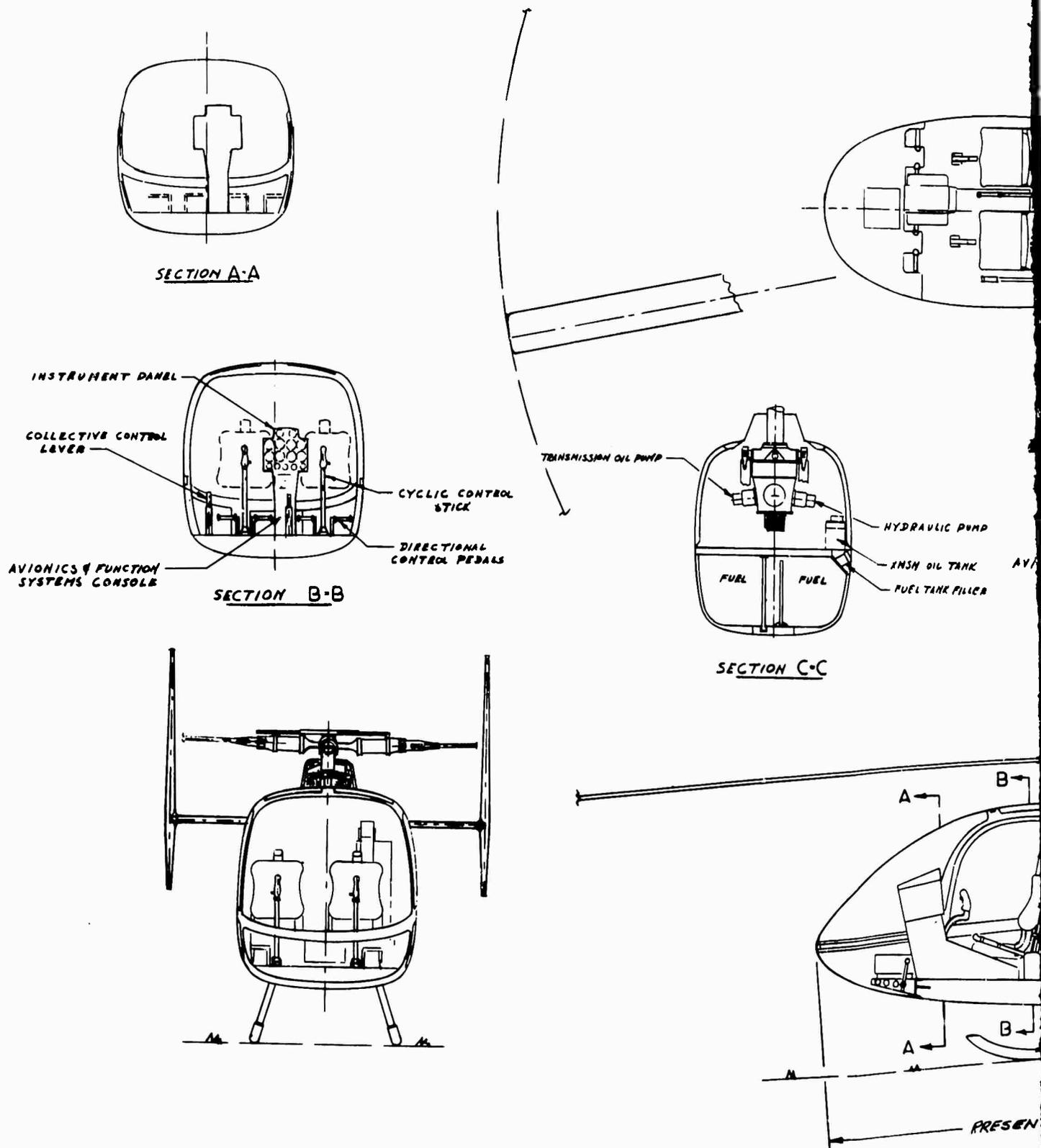
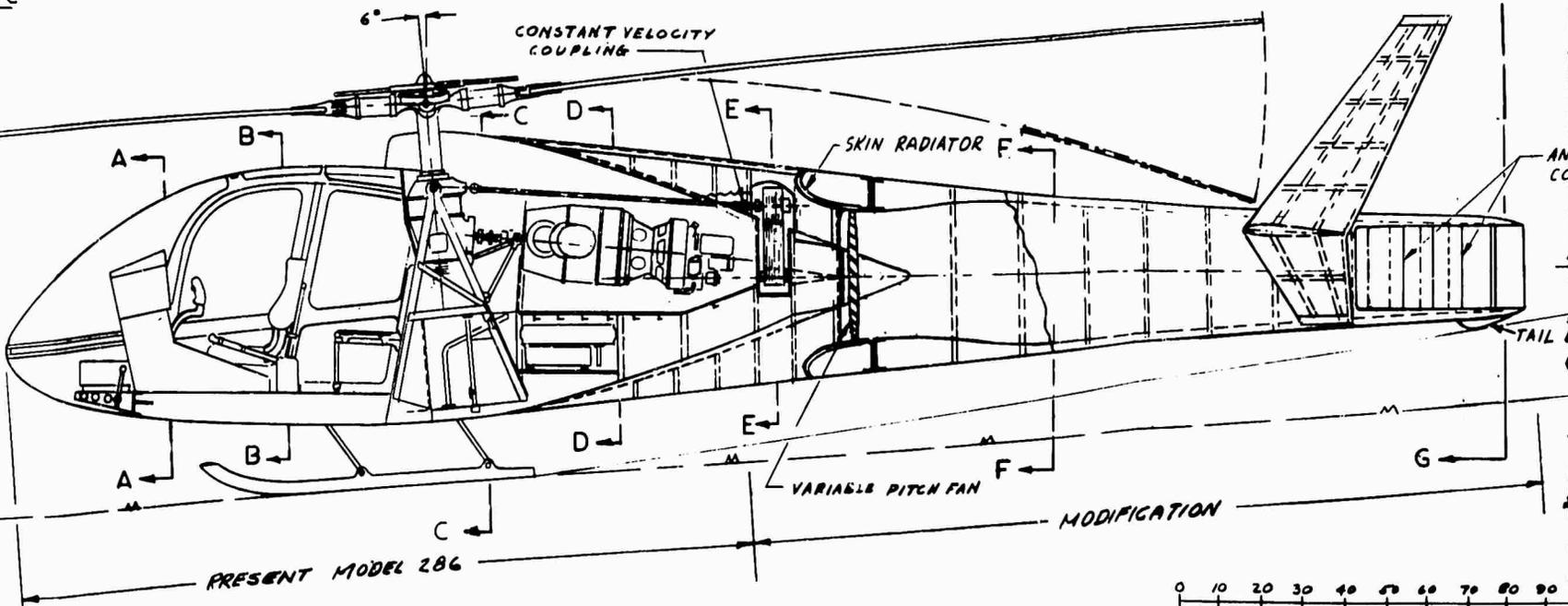
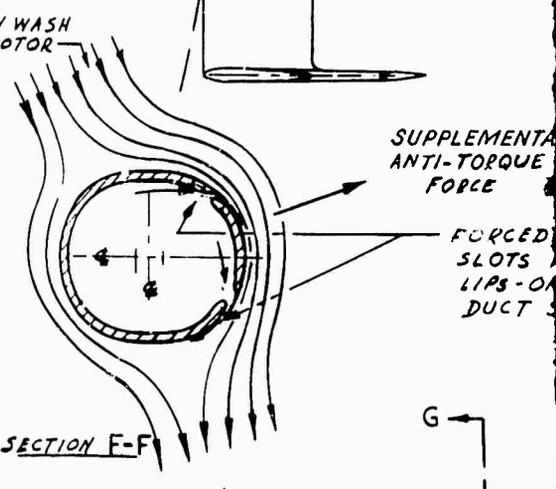
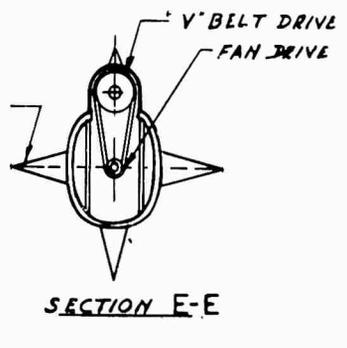
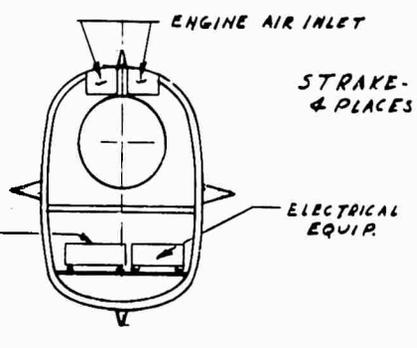
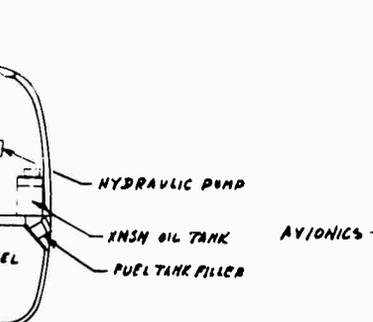
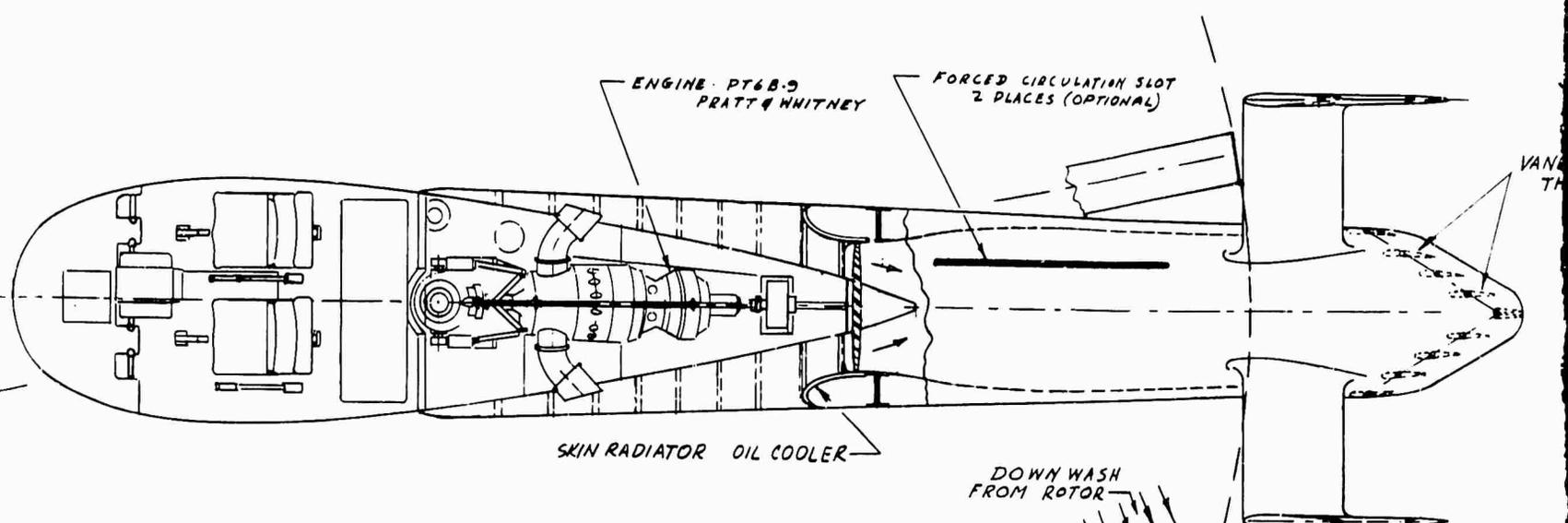
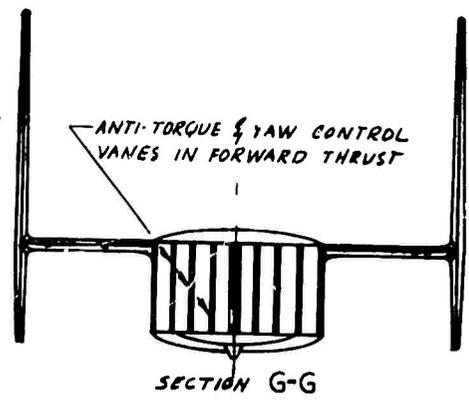
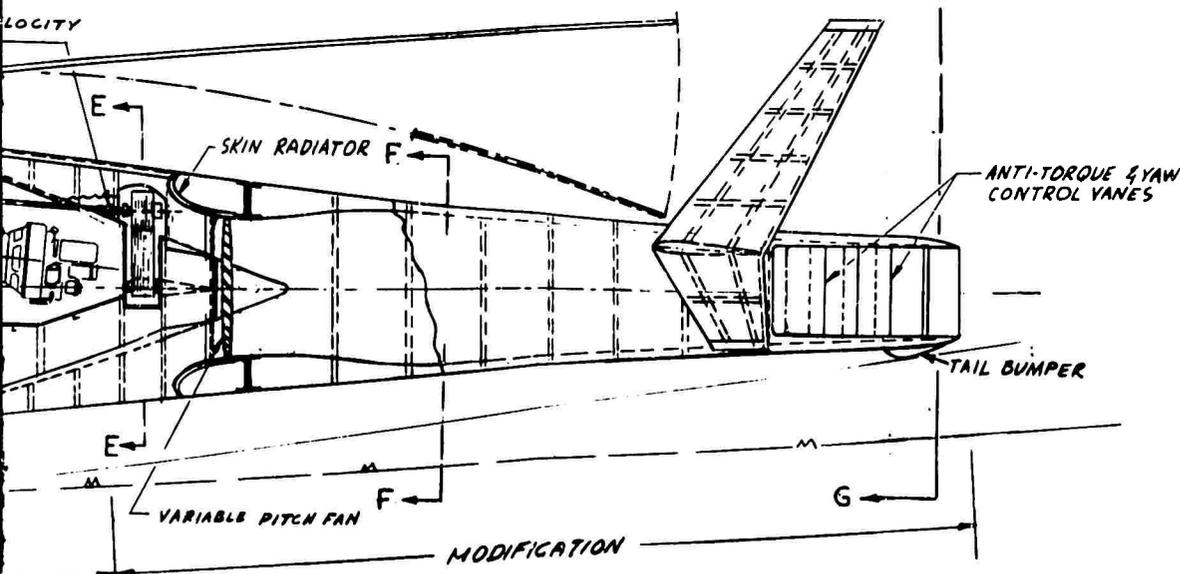
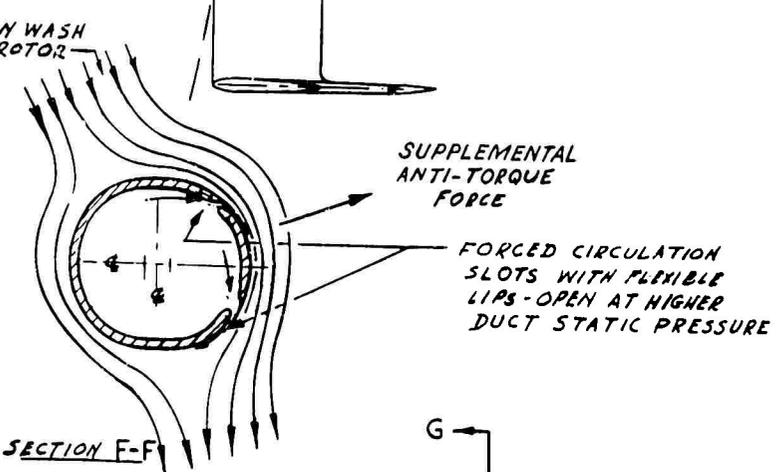
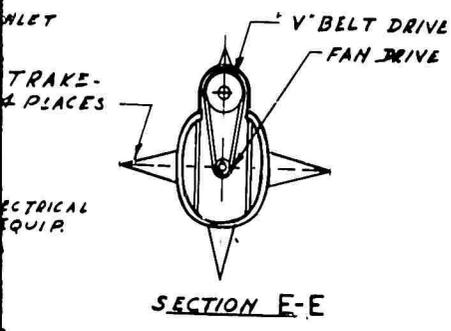
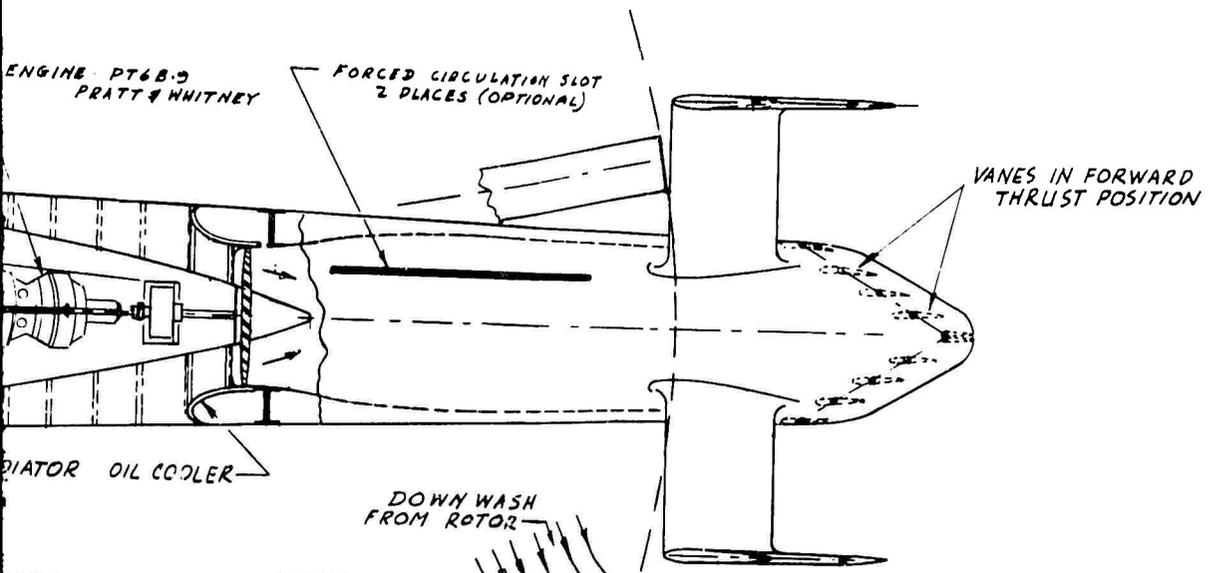


Figure 12. Internal Fan With Forced Circulation Augmentation.



45a



15a

45 k

MAIN ROTOR

DIAMETER 35. FT- 0. IN.
CHORD 13.5 IN.
DISC AREA 962. SQ. FT.
TIP SPEED - NORMAL 650. FT SEC

HORIZONTAL TAIL

AREA 10. SQ. FT.

VERTICAL TAIL

AREA 16 SQ. FT.

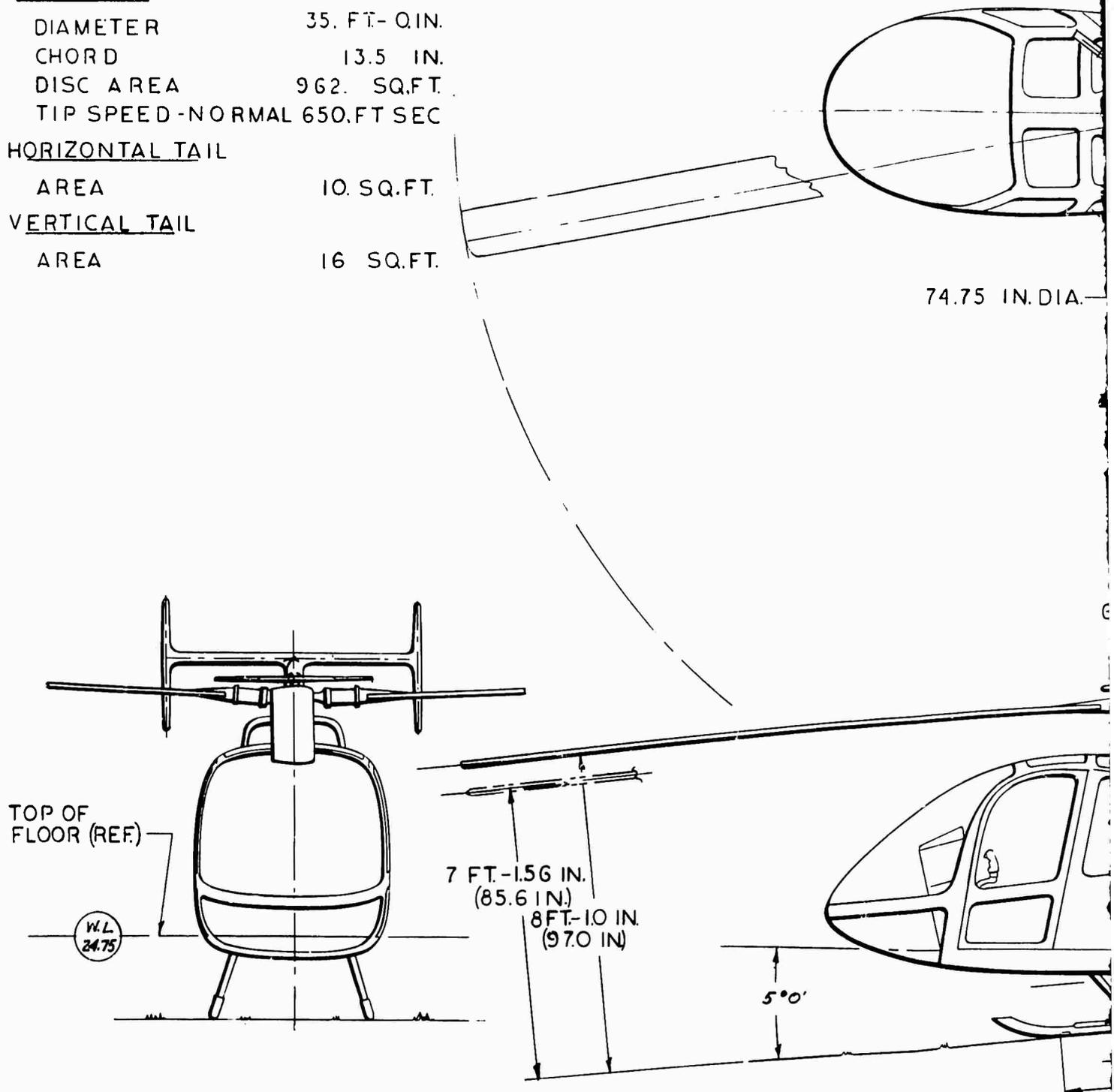
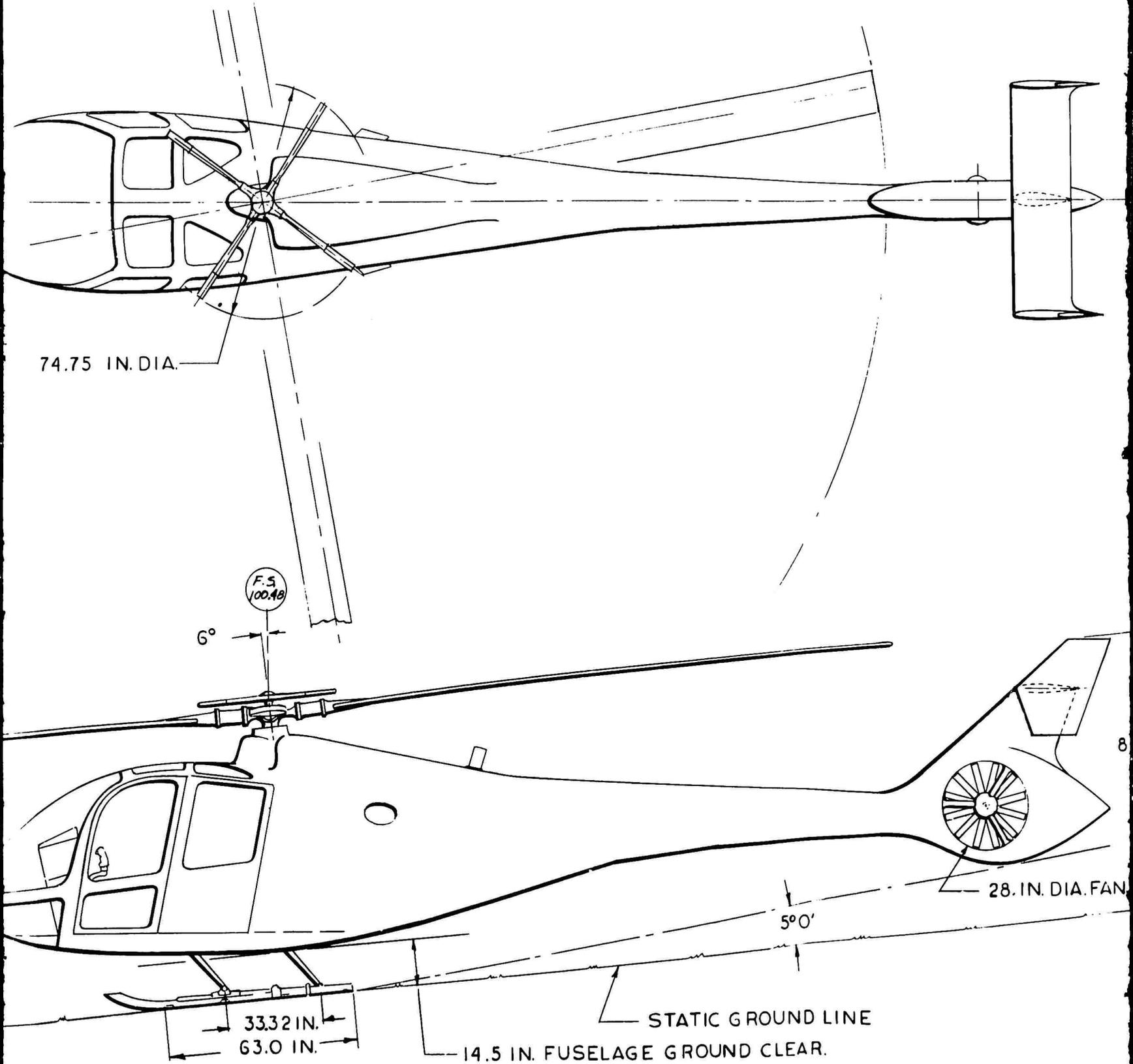
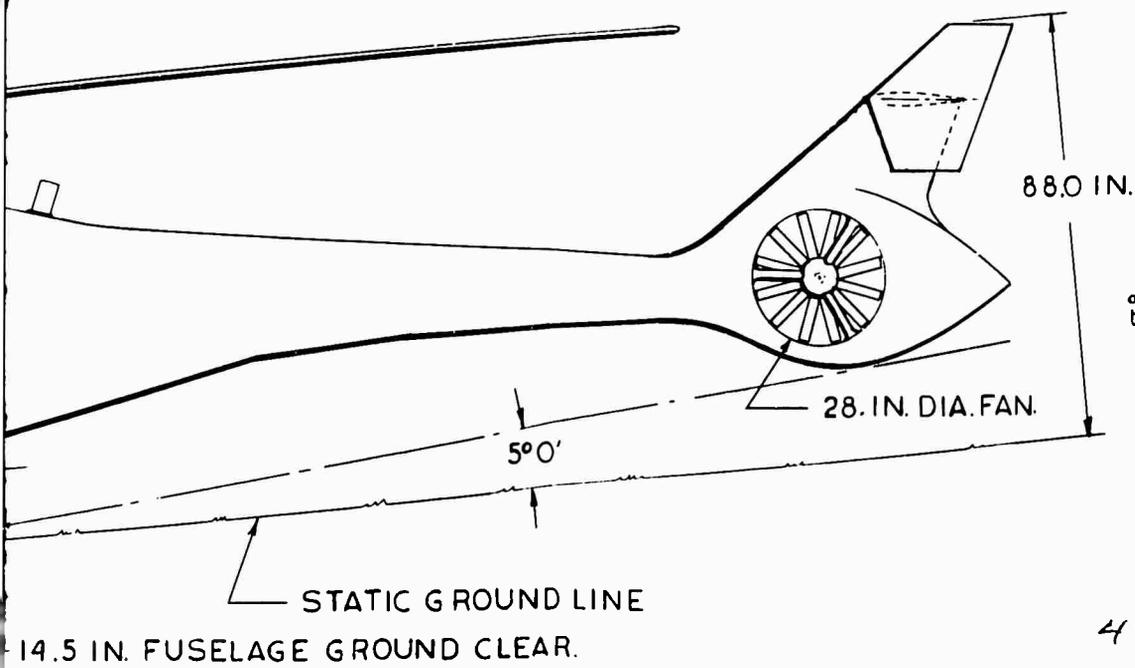
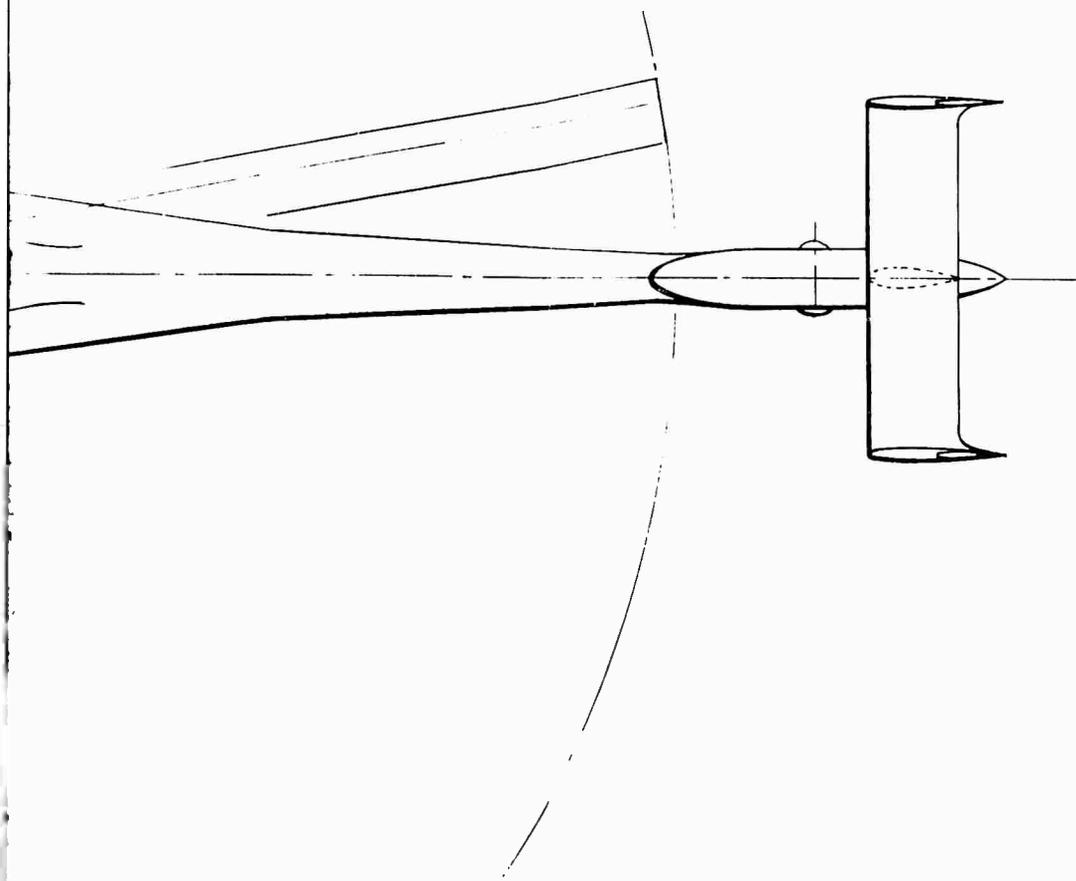


Figure 13. General Arrangement - 28-Inch Fan-in-Fin Concept.

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47a



47h

47a

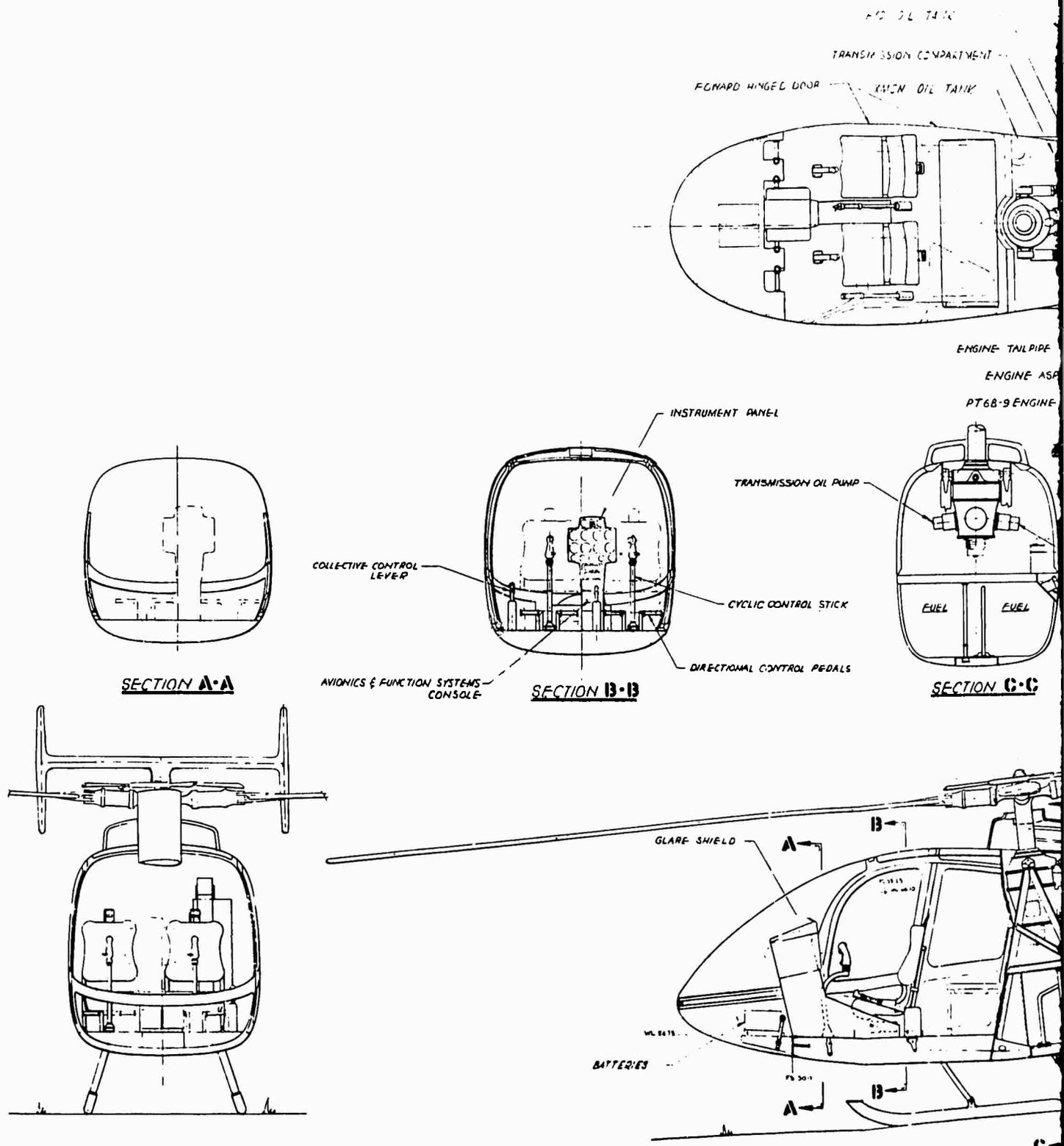
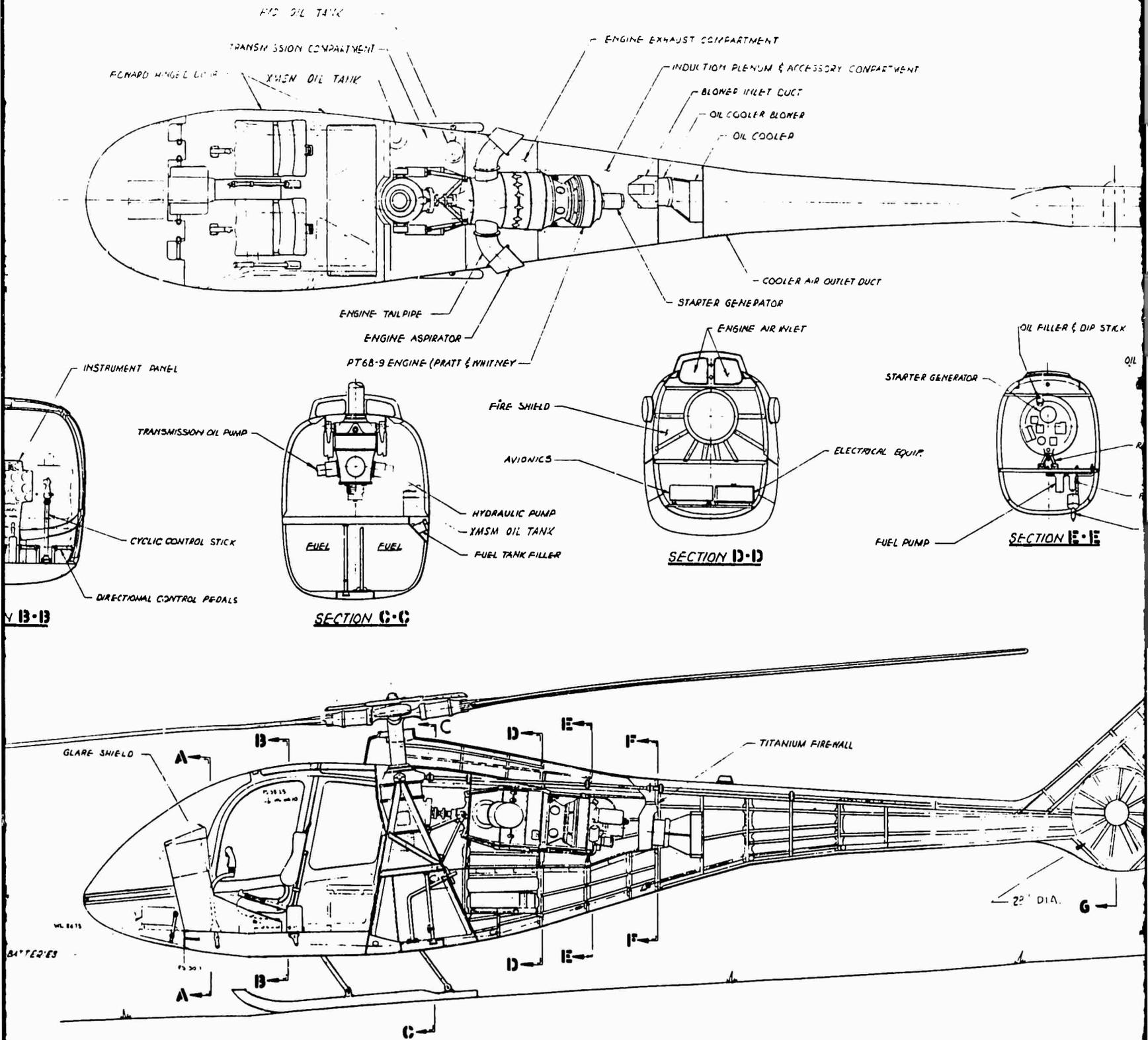


Figure 14. Inboard Profile - 28-Inch Fan-in-Fin Concept.

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ch Fan-in-Fin Concept.

49a

MUST COMPARTMENT

INDUCTION FLENUM & ACCESSORY COMPARTMENT

BLOWER INLET DUCT
OIL COOLER BLOWER
OIL COOLER

COOLER AIR OUTLET DUCT

STARTER GENERATOR

ENGINE AIR INLET

ELECTRICAL EQUIP.

SECTION D-D

OIL FILLER & DIP STICK

STARTER GENERATOR

OIL COOLER

REAR ENGINE MOUNT

FUEL STRAINER

FUEL PUMP

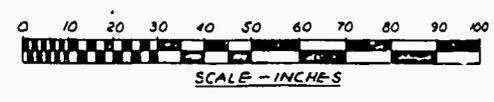
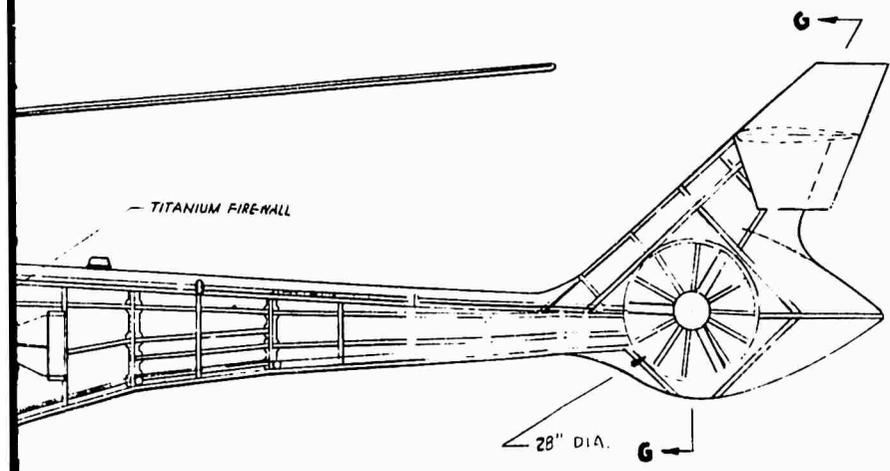
SECTION E-E

COMMON DRAIN MANIFOLD

SECTION F-F

BLOWER INLET DUCT

SECTION G-G



49 R

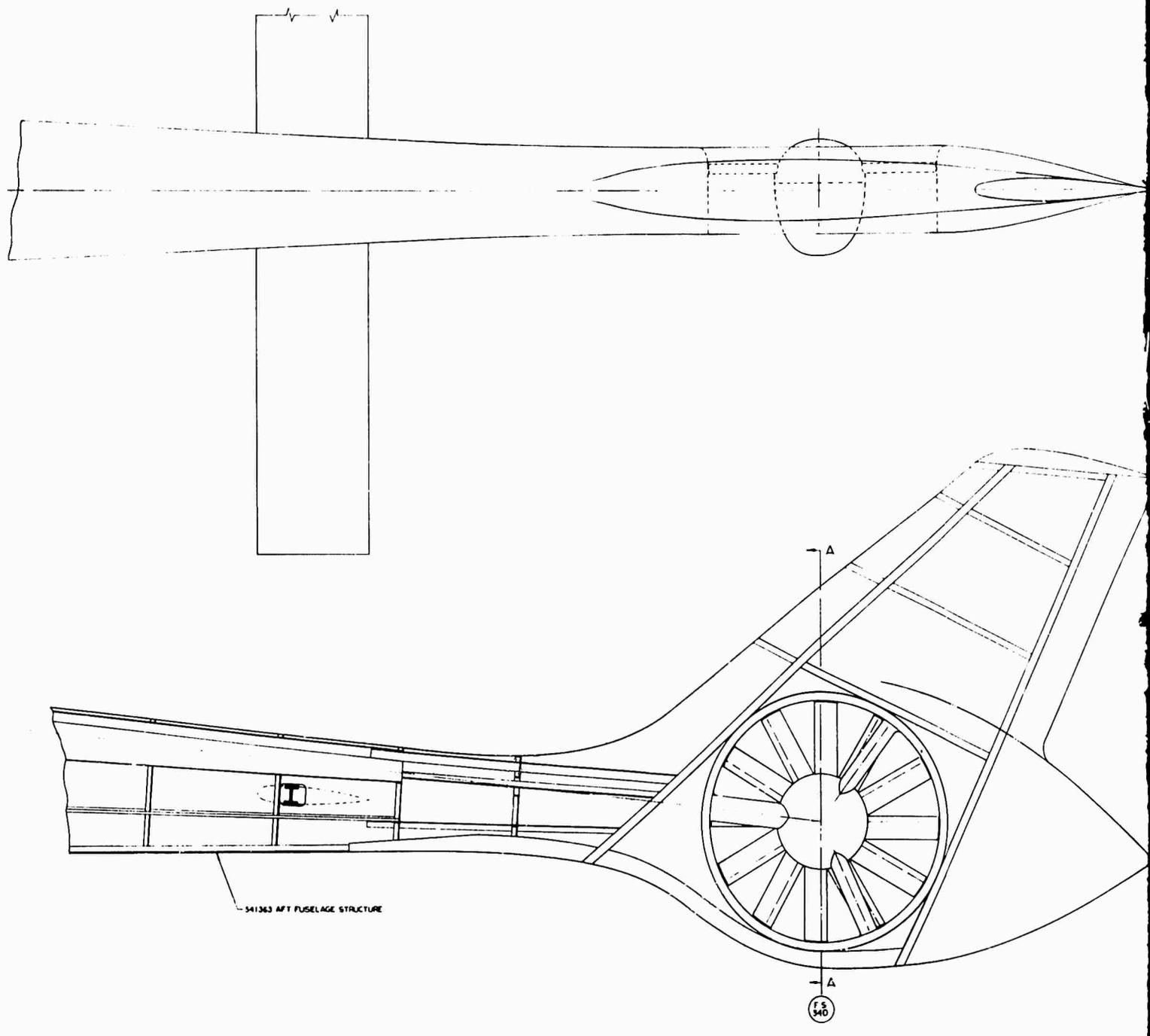
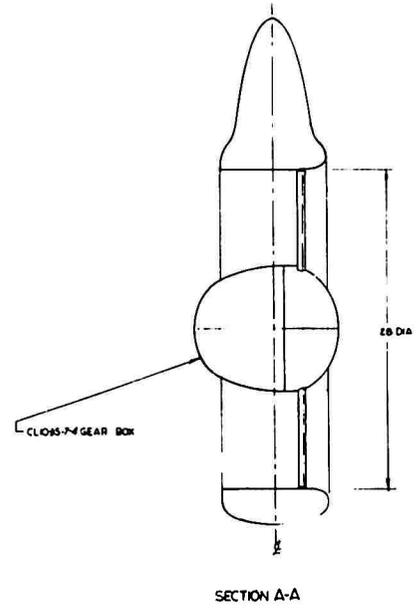
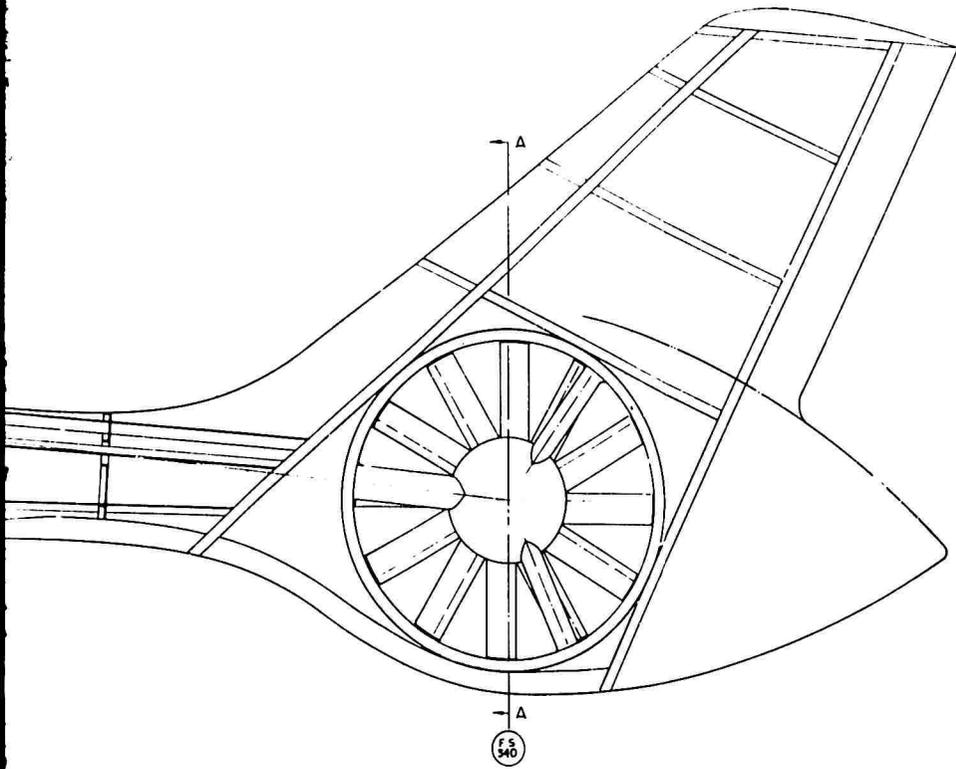
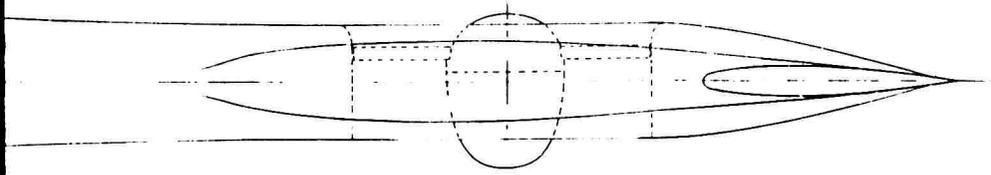


Figure 15. 28-Inch Fan-in-Fin Installation.

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GROUND LINE

-in-Fin Installation.

51a

28-Inch Fan-in-Fin with Flettner Rotor

Figure 16 shows a variation of the 28-inch fan-in-fin. A supplementary source of anti-torque force has been added by the incorporation of a Flettner (Magnus effect) rotor around the tail boom. Although a substantial force is obtainable, the complexity and weight penalties make this feature of questionable merit.

28-Inch Fan-in-Fin with Forced Circulation

Figure 17 shows another variation of the 28-inch fan-in-fin, with forced circulation slots along the tail boom for anti-torque augmentation. This system proved far more attractive than the Flettner system, and in combination with the larger aft fuselage of the internal fan configuration, it showed sufficient merit to qualify as an optional feature of the selected concept.

48-Inch Shrouded Fan

In order to cover a range of disc loadings for ducted fans, the 48-inch shrouded fan shown in Figure 18 was studied. The diameter selected is equivalent to the 6.5 ft diameter of the Model 286 tail rotor from the momentum energy point of view. The minimum shroud provides a nominal solution to the ground personnel and terrain contact problems. Flapping instabilities at high forward speeds are prevented by restraining the blade tips by means of runners attached to the blade tips operating in a channel within the shroud inner surface. Metal-to-metal contact between the runners and the guide channel is prevented by means of a film of air as in air bearings that utilize the air-cushion bearing principle. This large-fan approach was discarded in view of the marginal compliance with the design objectives and serious technical problem areas anticipated with the tip restraint mechanism.

Flettner Rotor as Primary System

Figure 19 shows the results of a brief study to determine the characteristics of a system employing a Flettner rotor of sufficient size to develop the total required anti-torque moment for hovering plus the maneuverability increment. It was found to have excessive weight, complexity, and drag. Furthermore, with single rotation, control response vanishes and then reverses during transition from powered flight to autorotational descent. However, a related system, namely the forced circulation concept described previously, is an acceptable method of anti-torque augmentation in powered hovering flight.

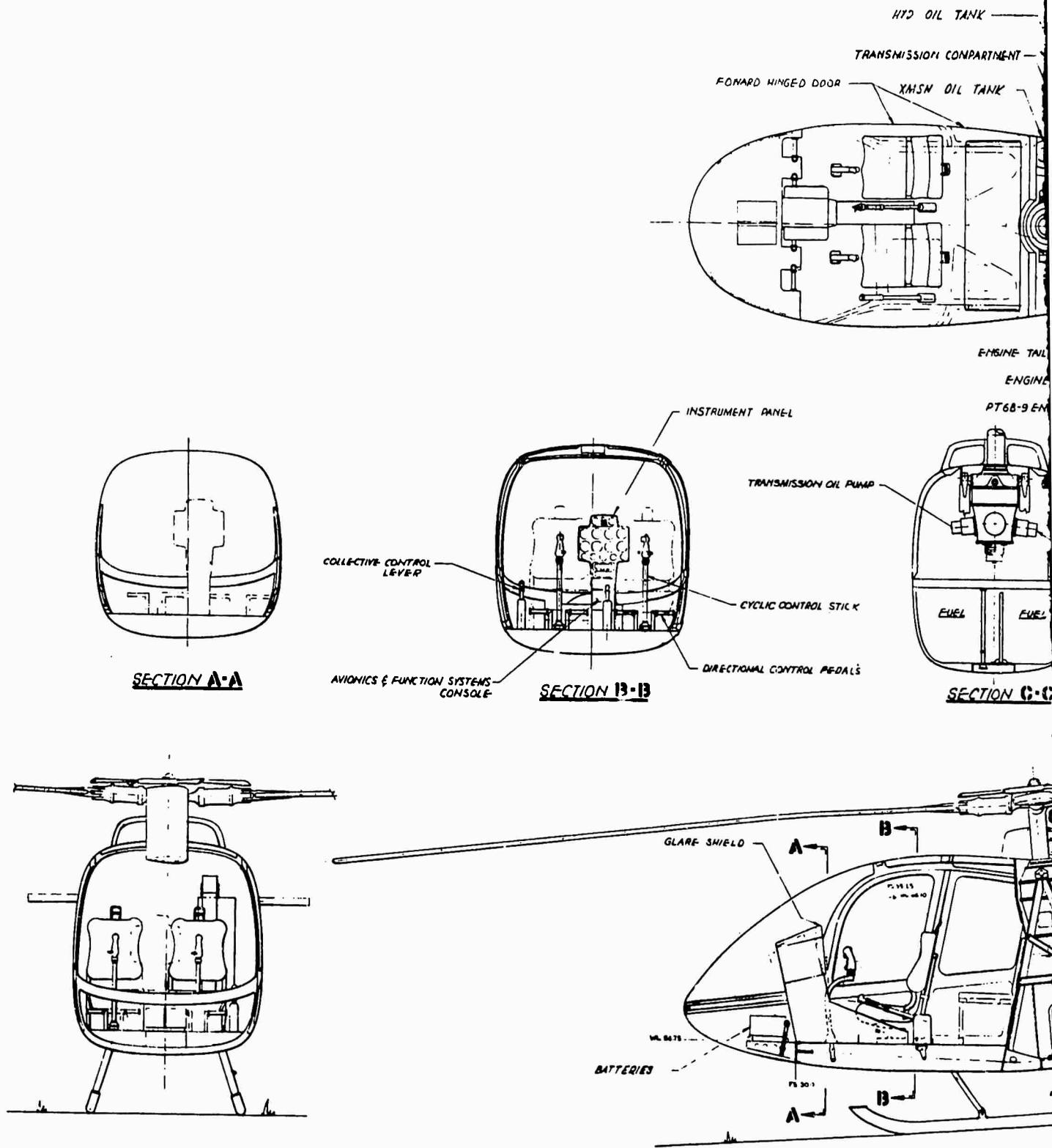
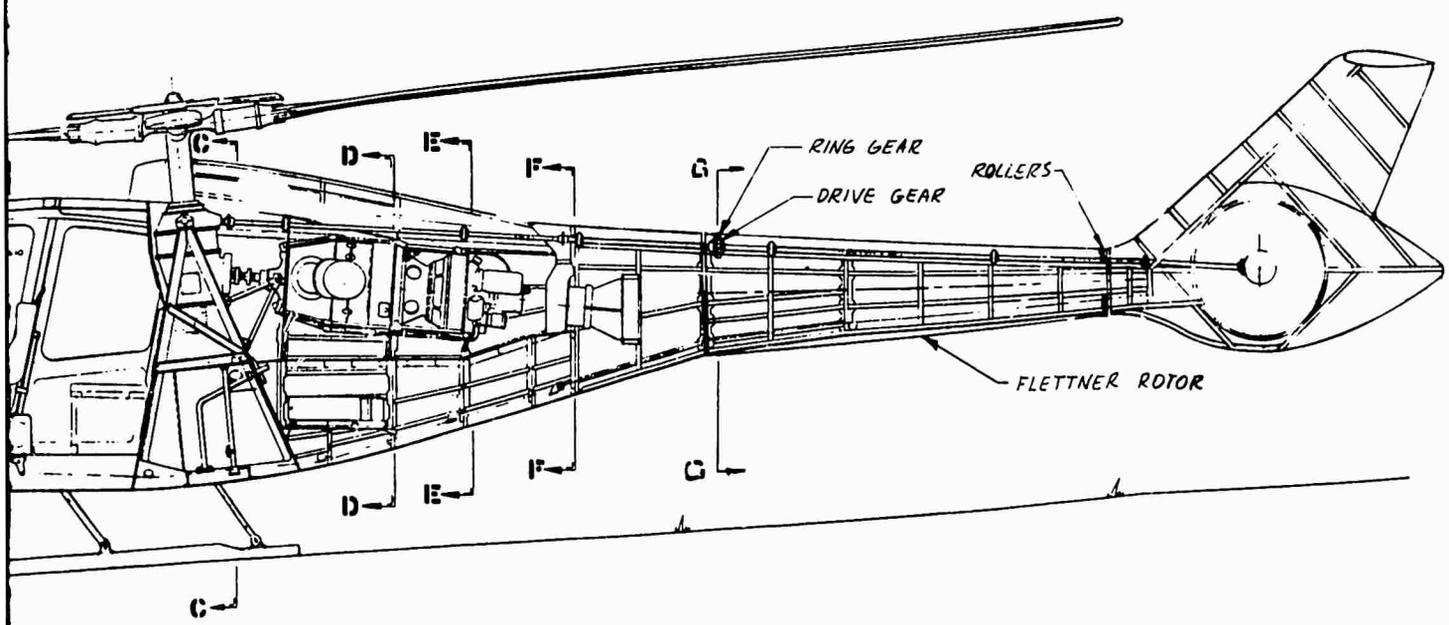
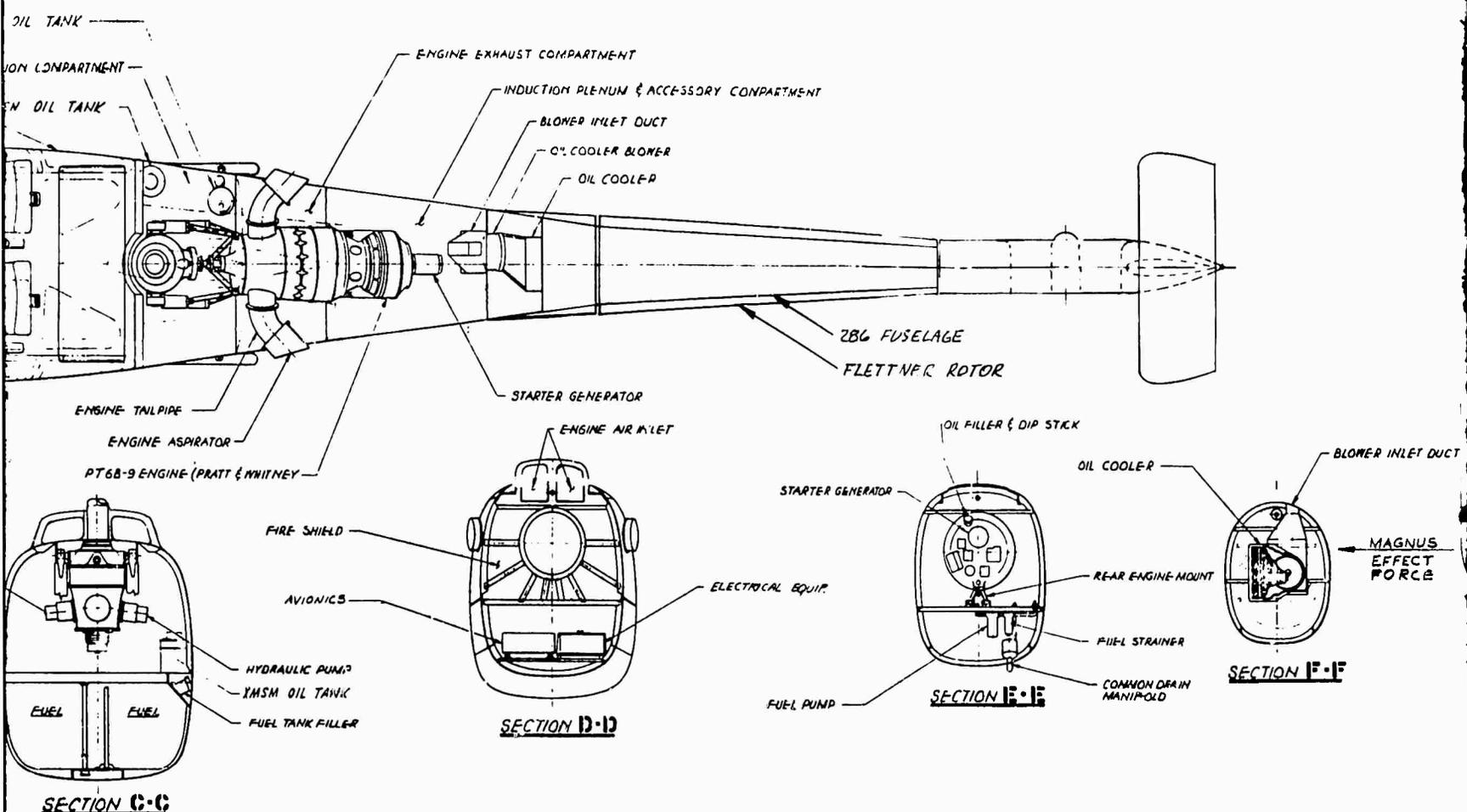


Figure 16. 28-Inch Fan-in-Fin With Flettner Rotor Augmentation.

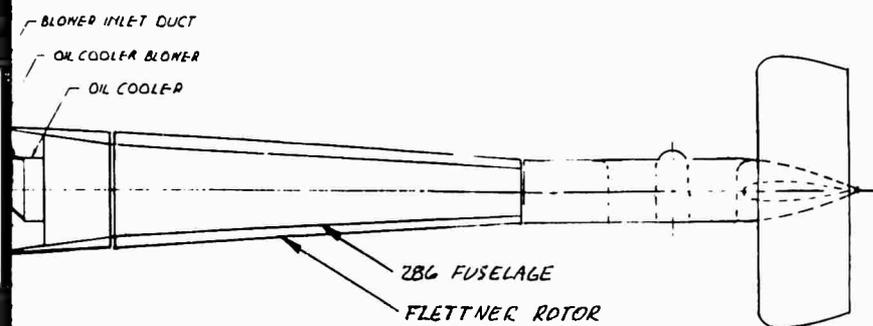
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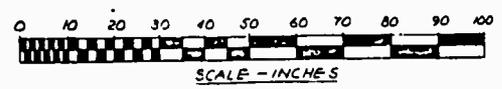
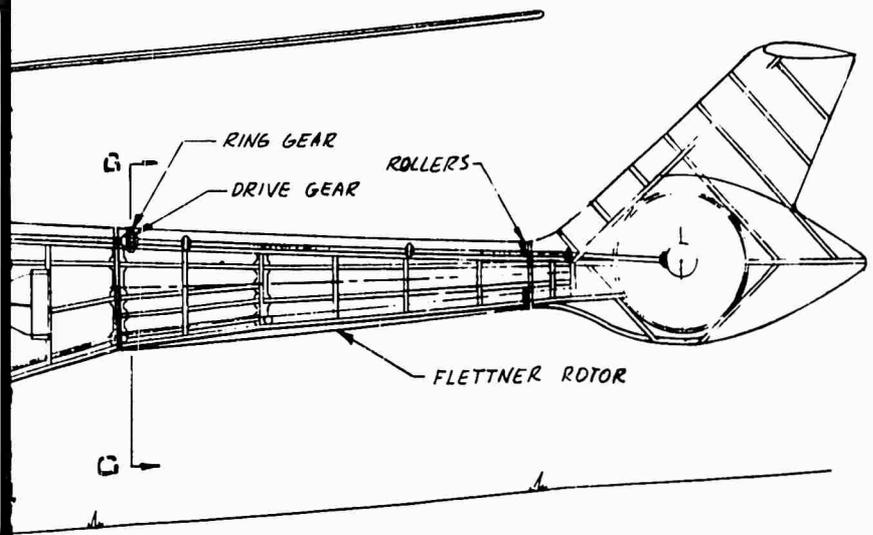
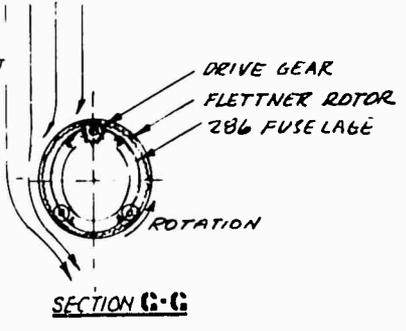
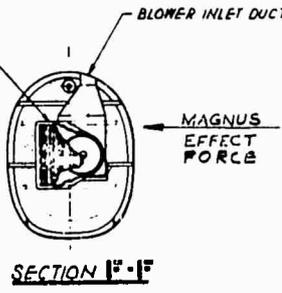
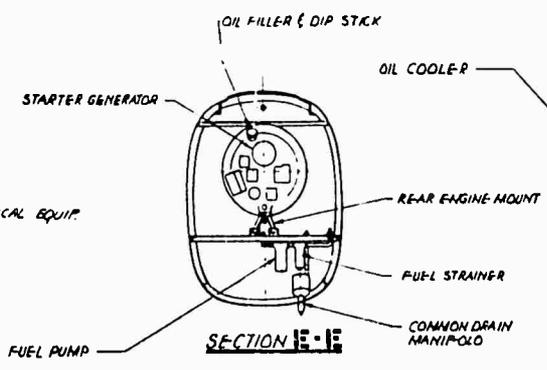
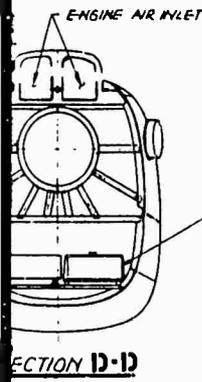
55a

55a

ST COMPARTMENT
INDUCTION PLENUM & ACCESSORY COMPARTMENT



STARTER GENERATOR
ENGINE AIR INLET



552

5a

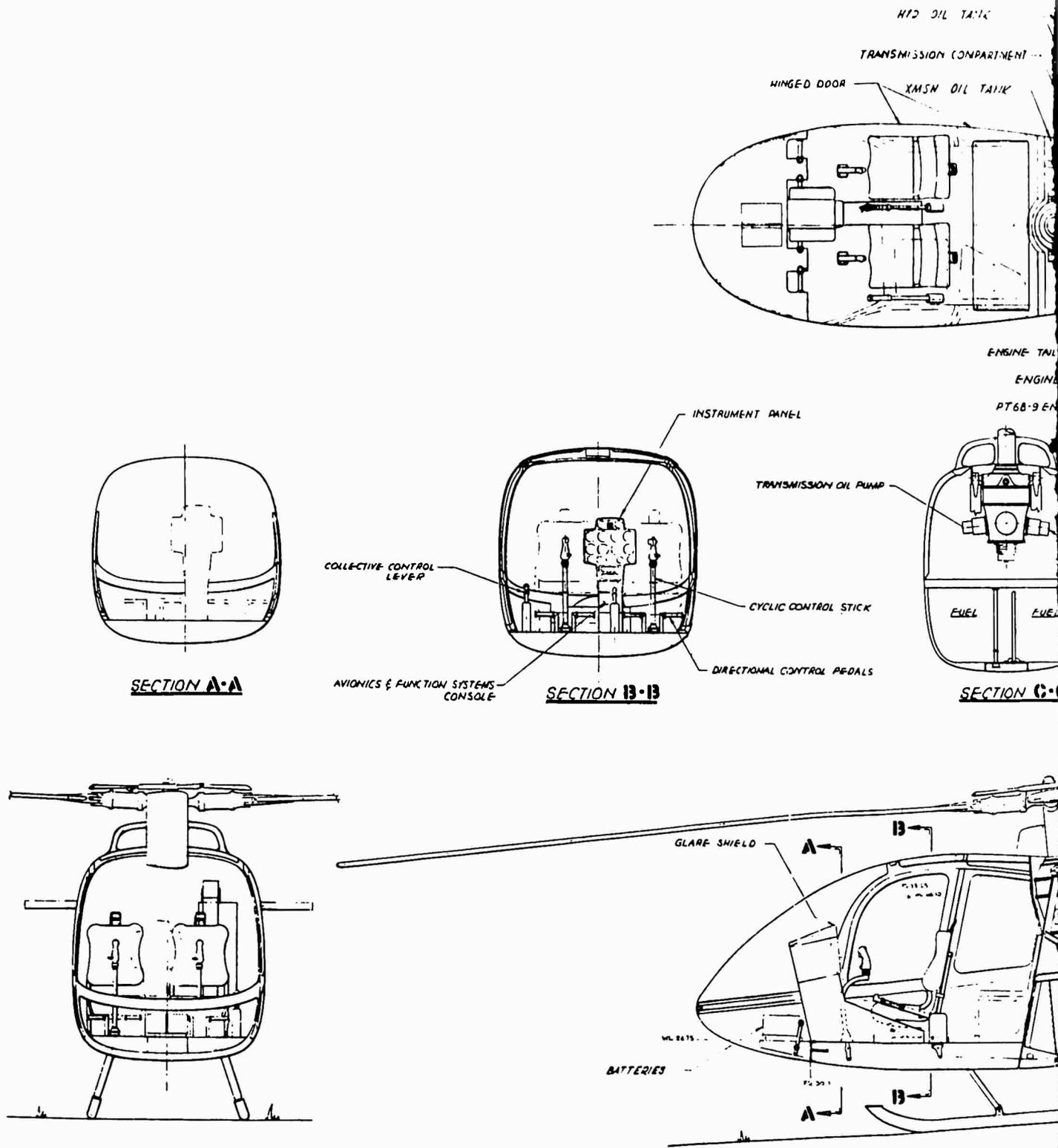
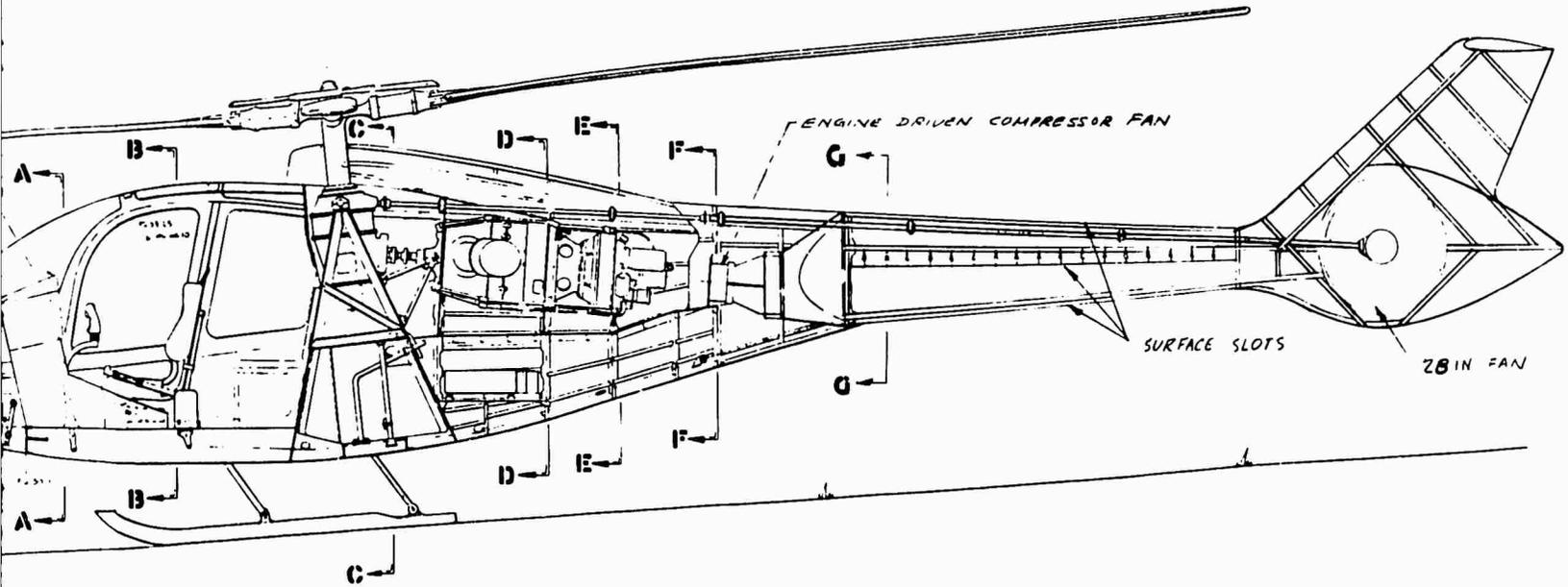
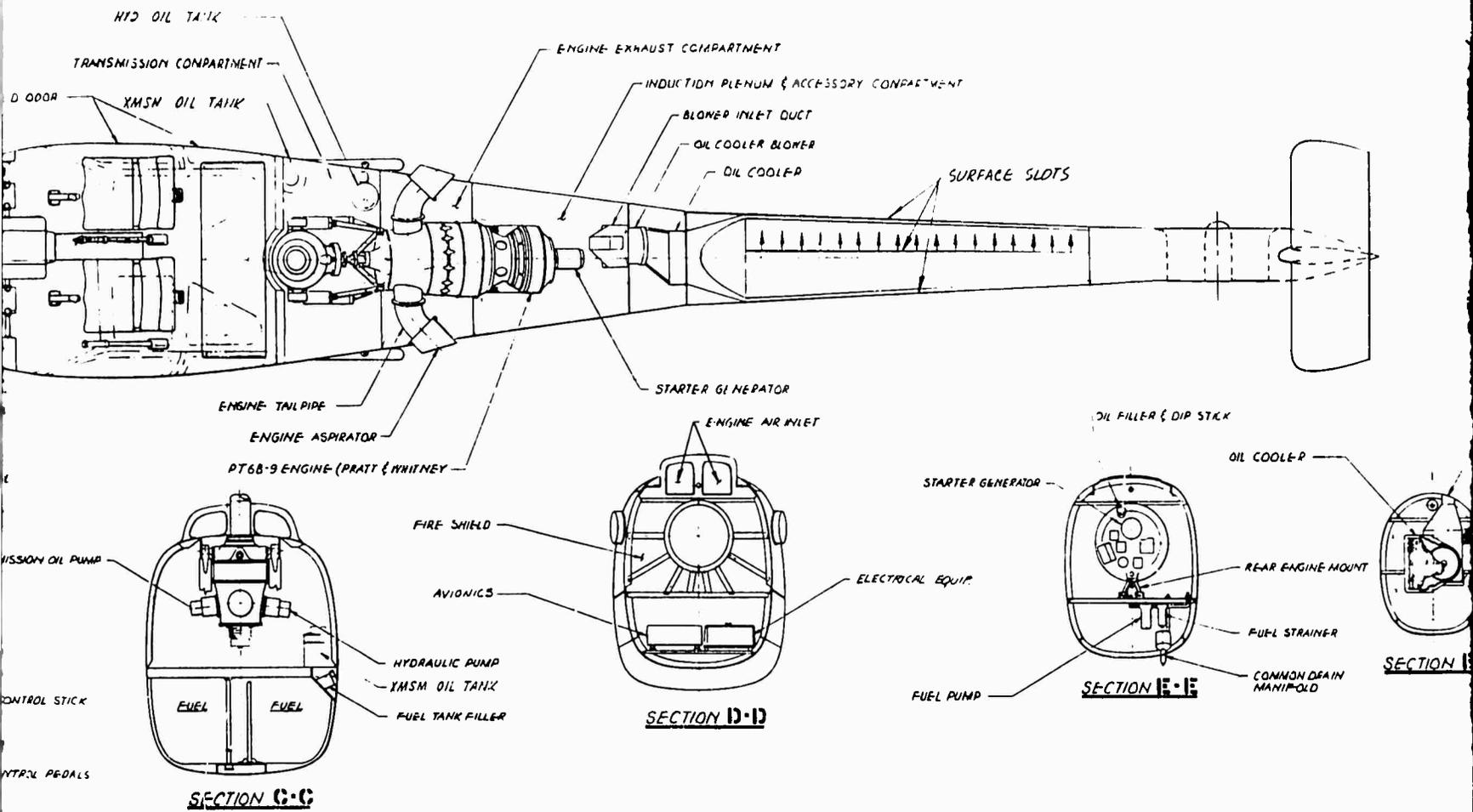
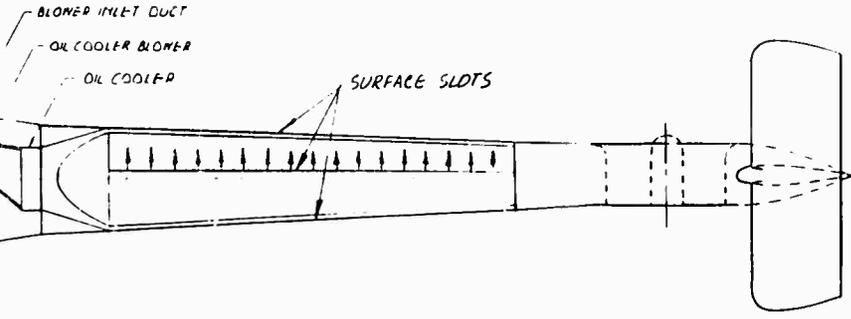


Figure 17. 28-Inch Fan-in-Fin With Forced Circulation Augmentation.

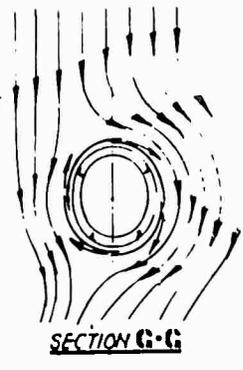


57a

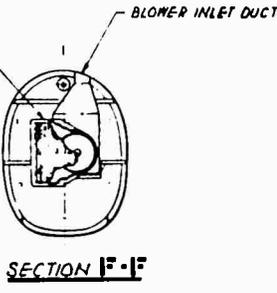
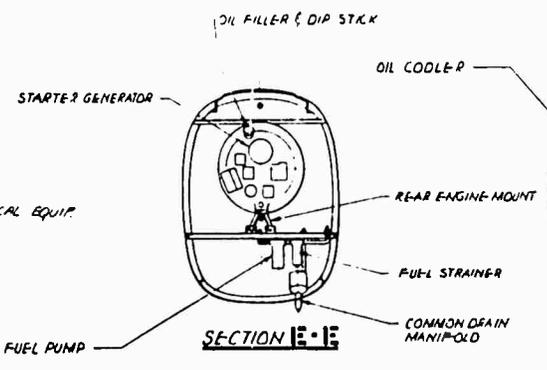
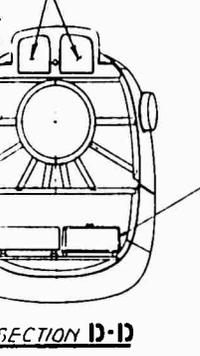
1ST COMPARTMENT
 2ND TION PLENUM & ACCESSORY COMPARTMENT



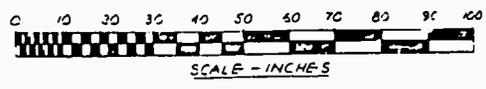
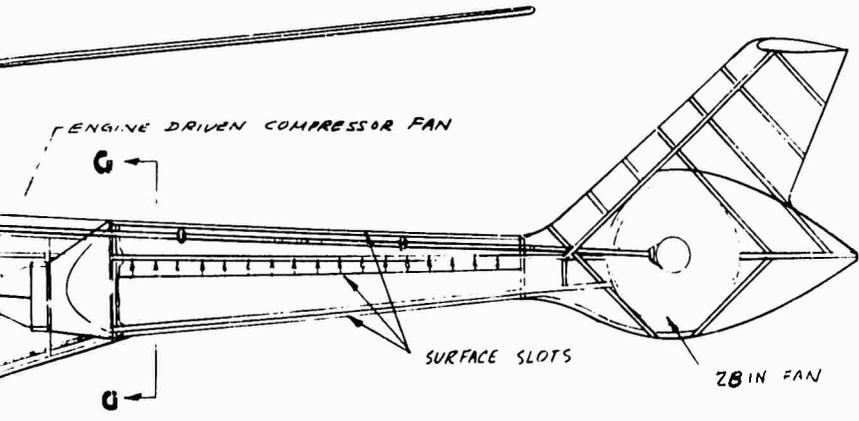
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STARTER GENERATOR
 ENGINE AIR INLET



SECTION G-G



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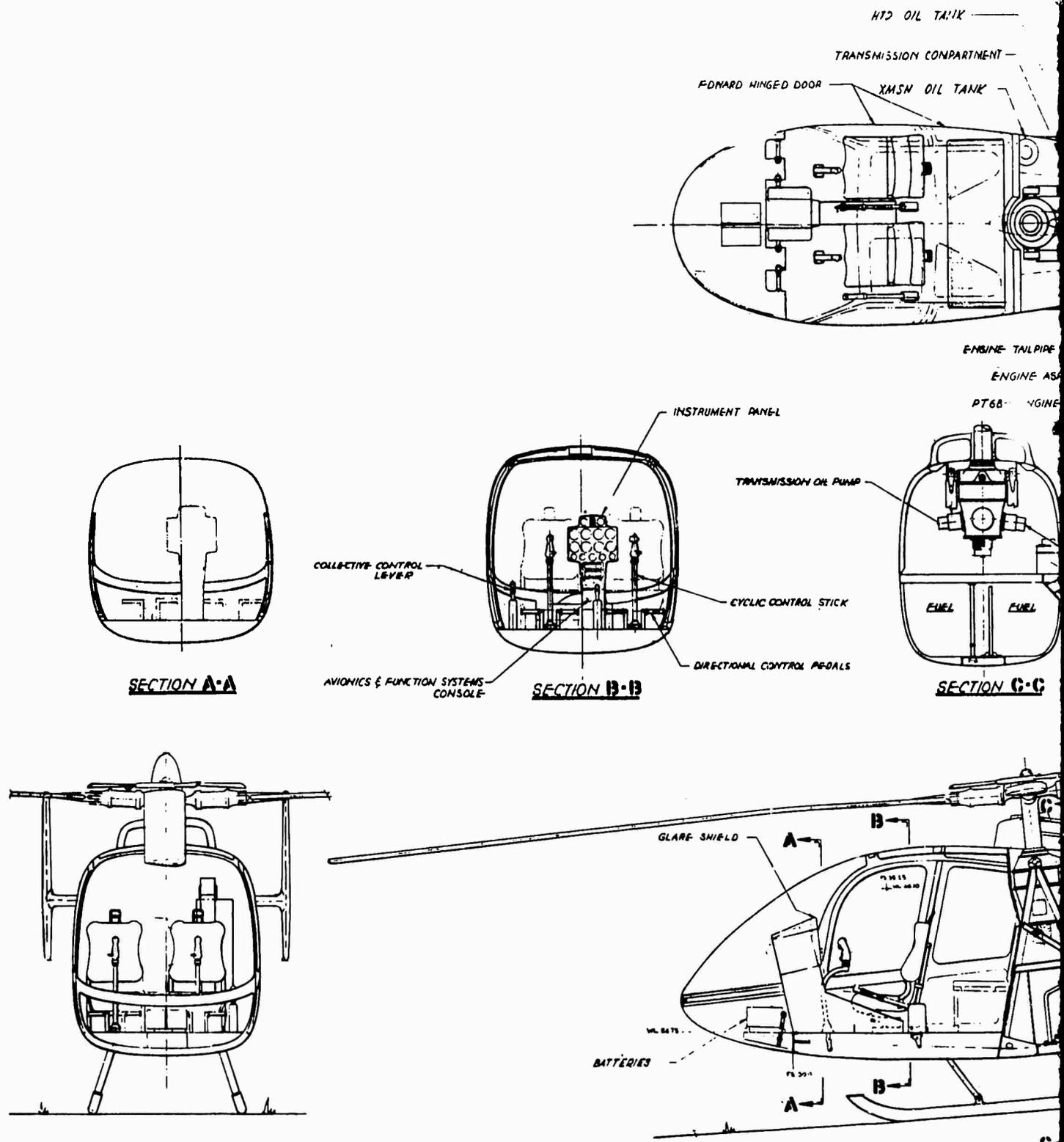
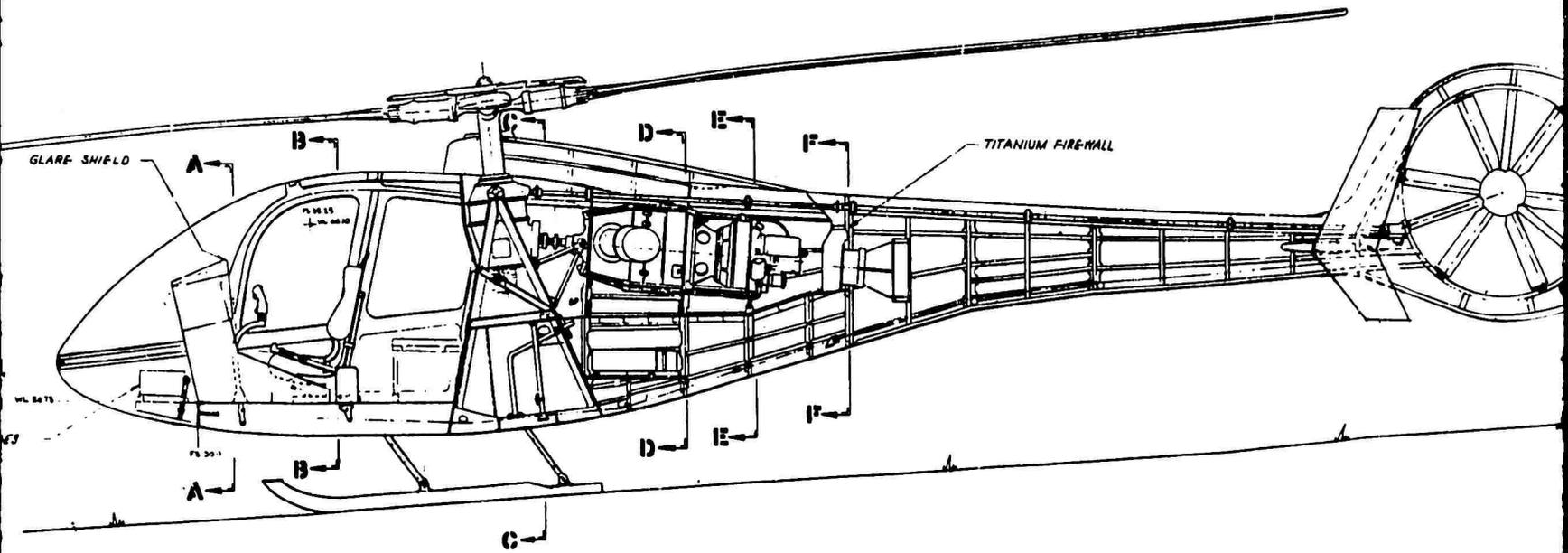
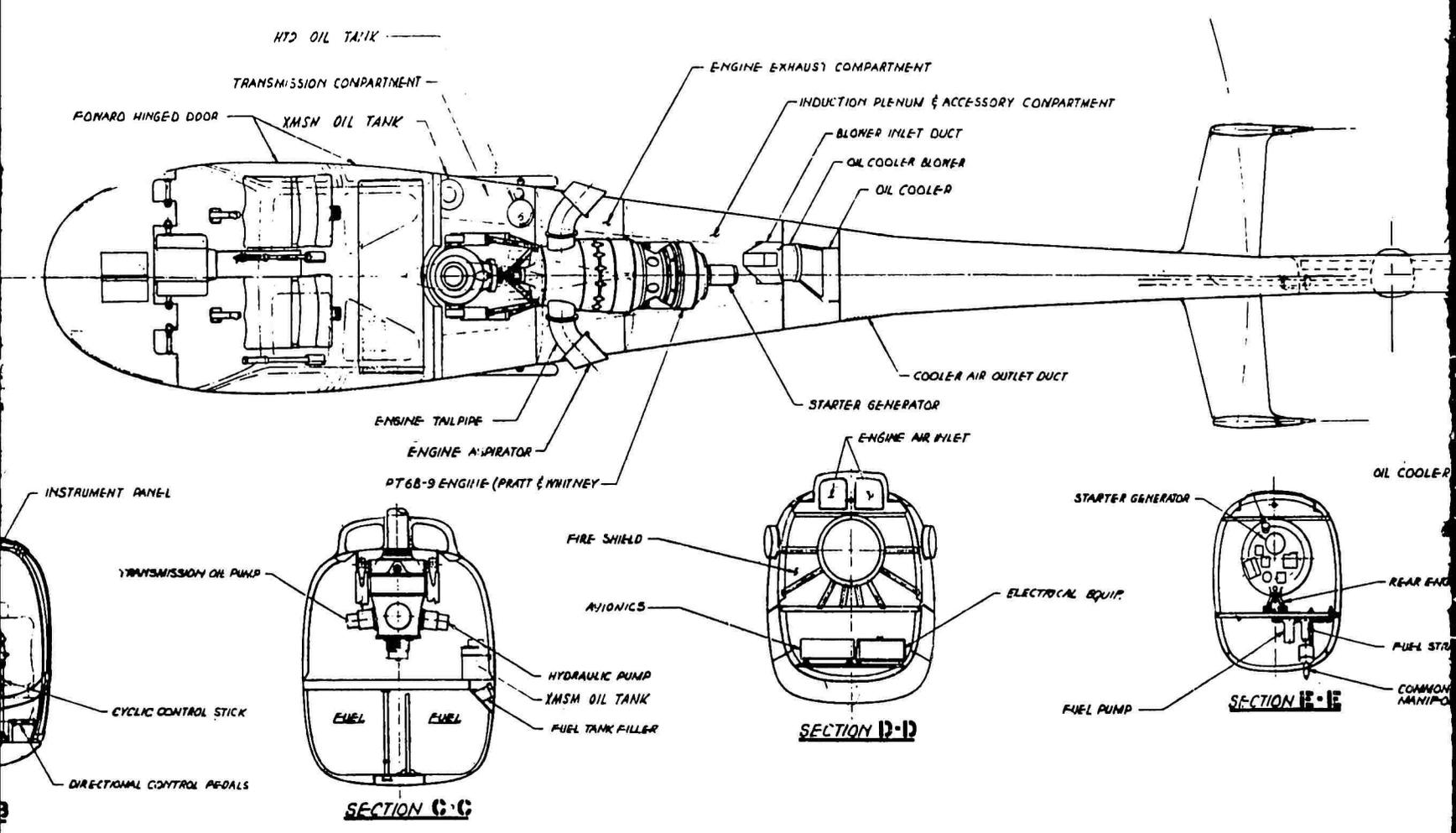
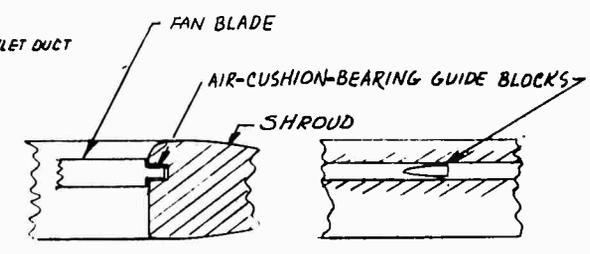
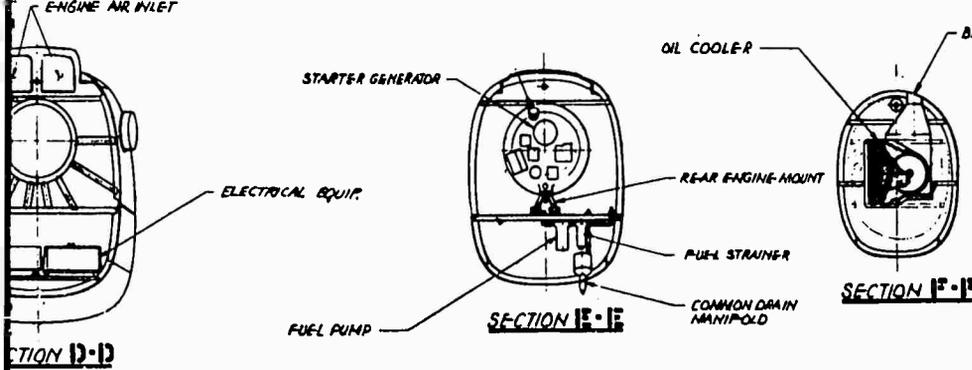
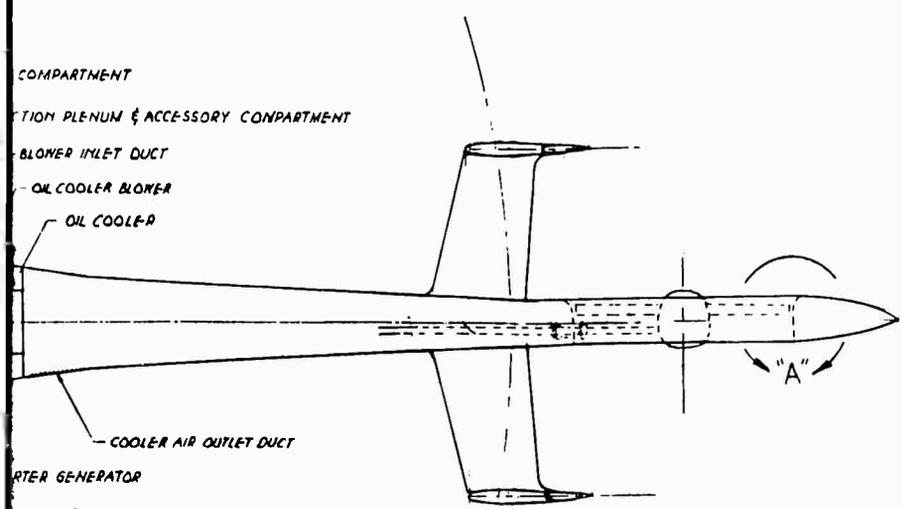


Figure 18. 48-Inch Shrouded Fan Concept.

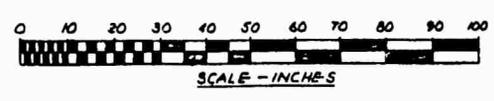
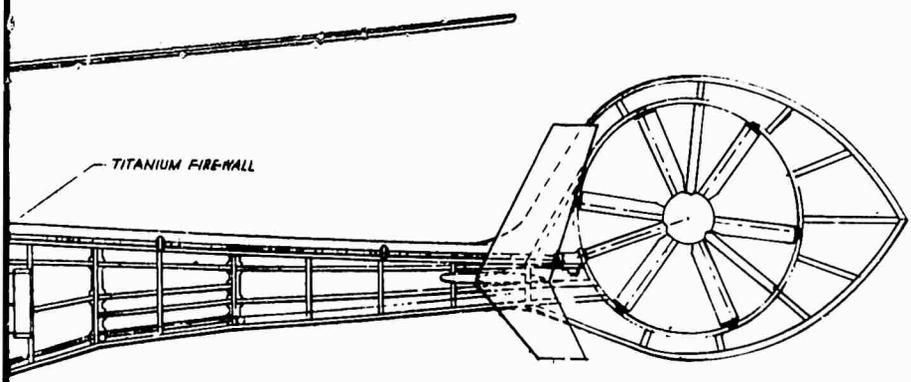
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FAN BLADE TIP RESTRAINT
 DETAIL "A"



59a

59b

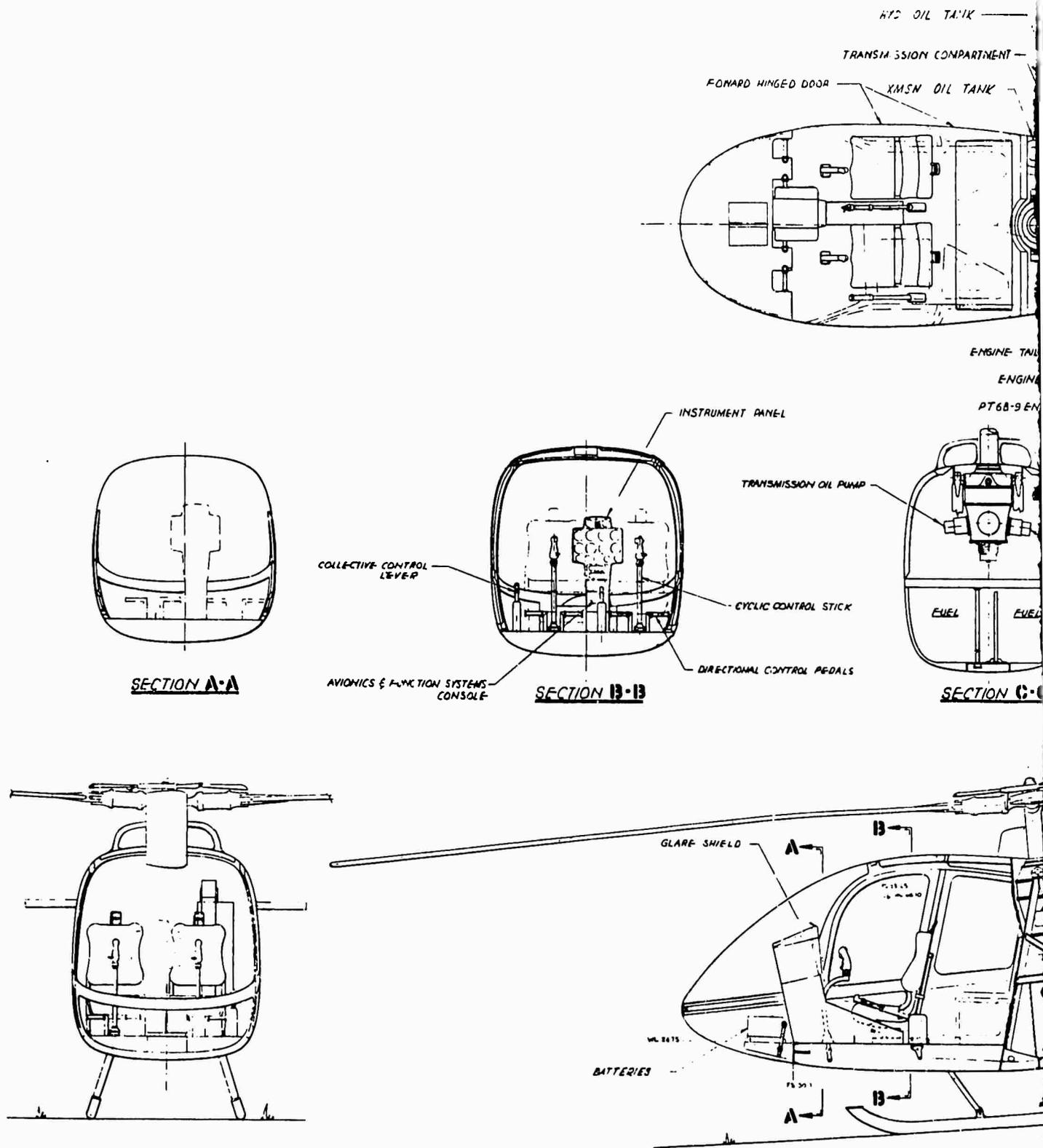
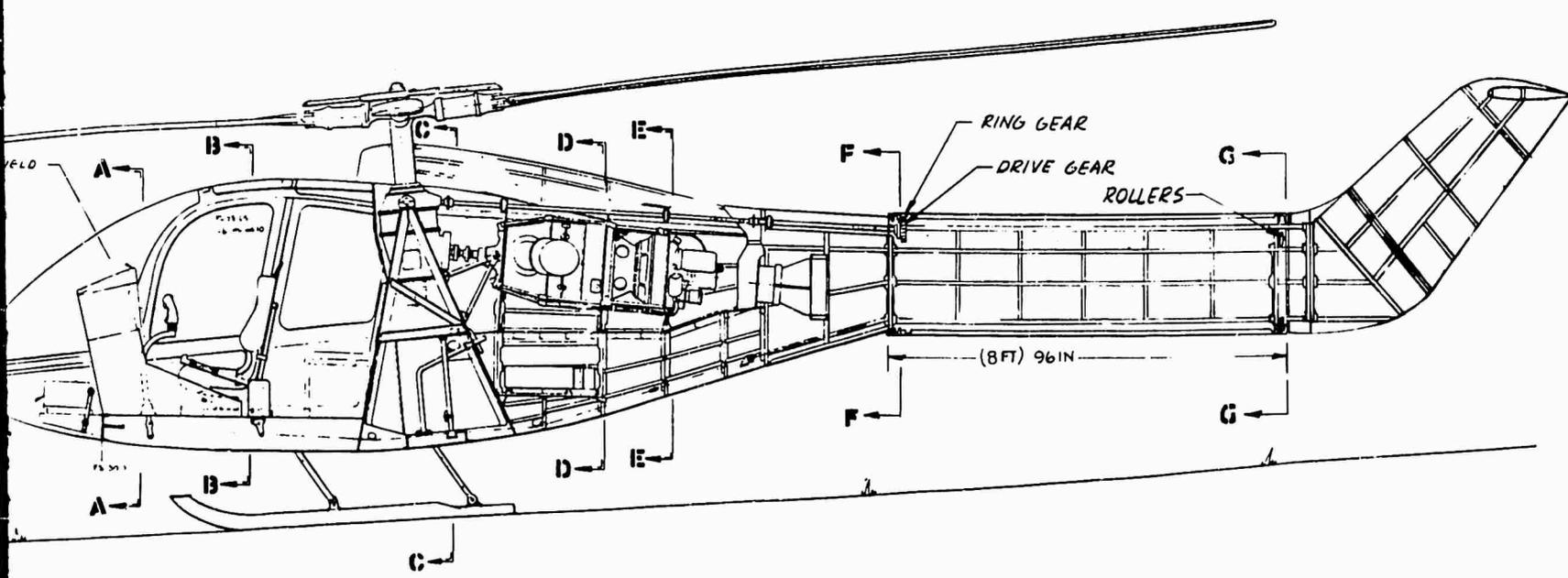
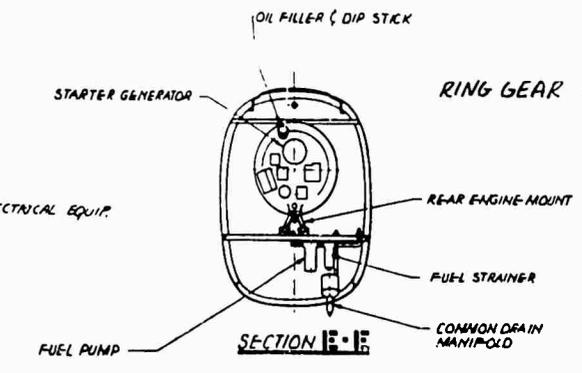
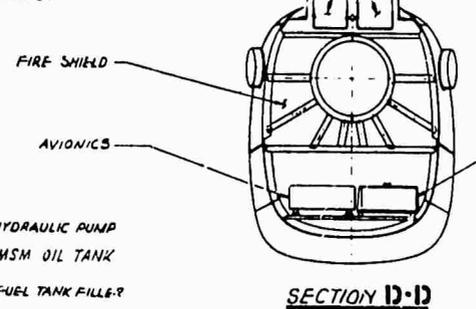
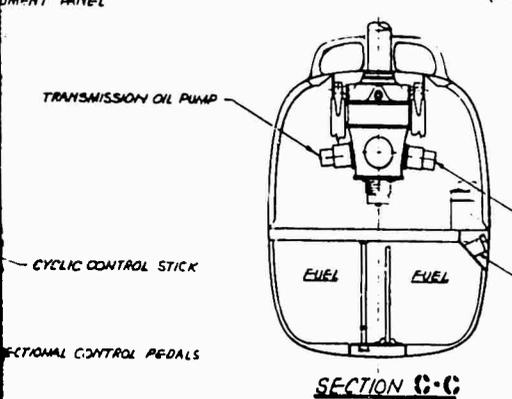
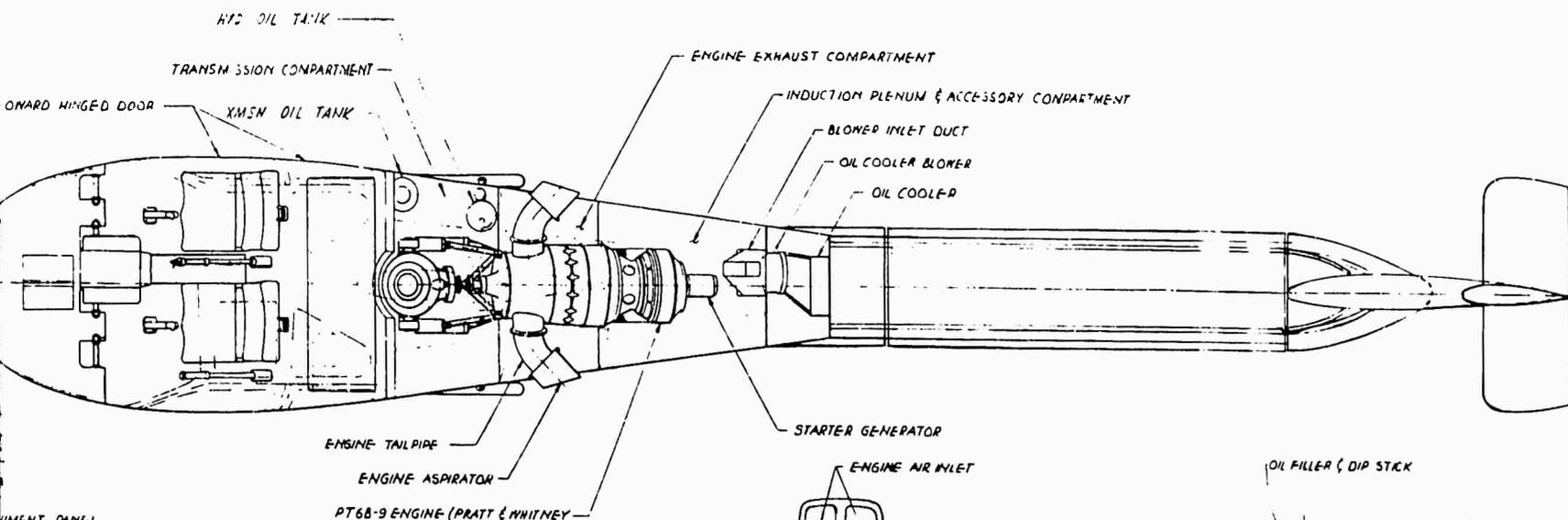
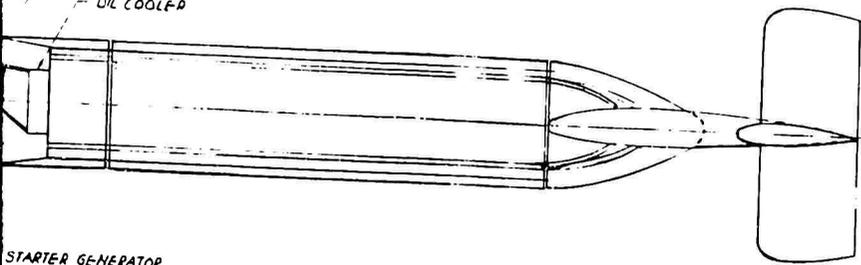


Figure 19. Flettner Rotor Primary System Concept.



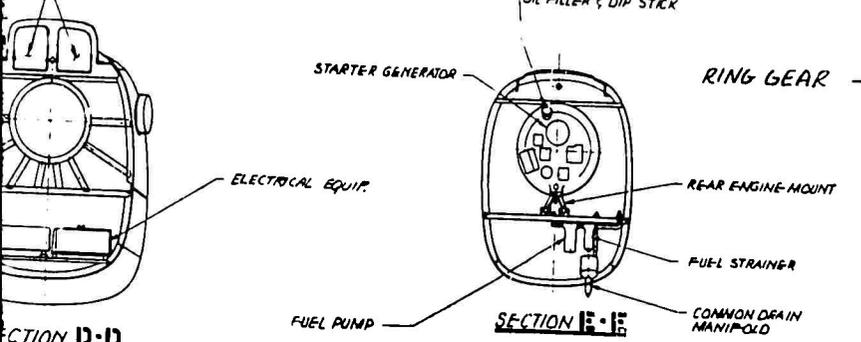
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 OIL COOLER



STARTER GENERATOR

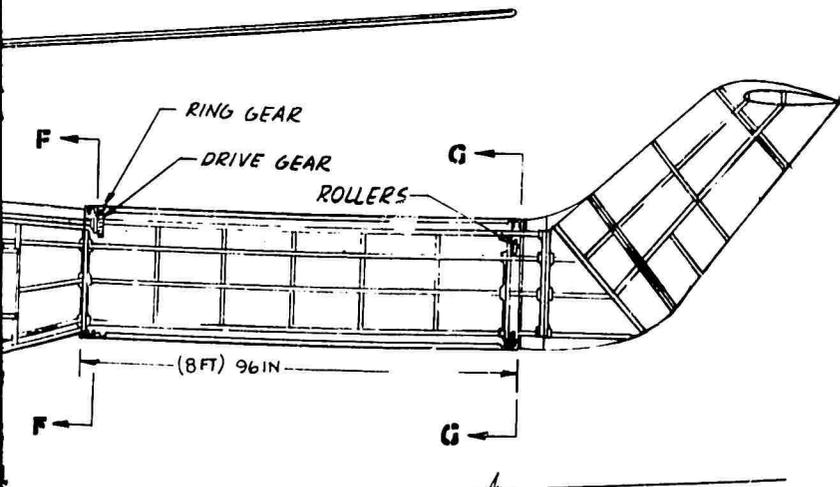
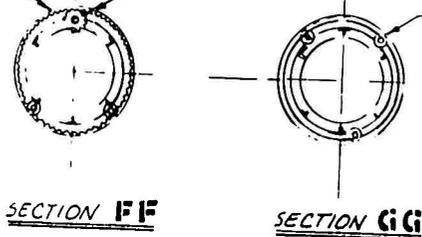
ENGINE AIR INLET



RING GEAR

DRIVE GEAR

ROLLERS



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5. WEIGHT DATA

This section presents weight data for the selected concepts as applied to a Lockheed Model 286 helicopter. Data are presented in the form of tabulated side-by-side comparisons of the various configurations and the basic Model 286.

Table III summarizes the component weights for five aircraft:

- The existing Model 286, which has a conventional tail rotor and thus becomes the basis for comparison of the proposed new concepts.
- Two variations of the baseline aircraft, denoted "modified 286." These two columns of weight show, when compared to the baseline figures in the first column, the weight changes estimated for modifying the existing test aircraft to incorporate the fan-in-fin and the internal fan concepts.
- Two additional versions of aircraft using the same two new anti-torque concepts. In these cases, the aircraft are similar to the modified configurations, except that instead of merely adapting new hardware to the existing Model 286 aircraft, these weights are estimated on the basis that totally new aircraft would be designed to apply the concepts in an optimum manner without the compromises required in a retrofit modification program. In order to maintain continuity and correlation with Model 286 weight data, the weights for the totally new aircraft do not incorporate the benefits of advanced state-of-the-art design, and, furthermore, retain the weight penalties inherent in the design philosophy of the Model 286 which was designed as a company-funded demonstrator for FAA certification with maximum structural integrity and minimum design, tooling, and development cost.

The table shows reductions in gross weights for the "modified" configurations. The reductions are a result of the manner selected for making the comparison such that the cost (in terms of payload reduction) of implementing design changes to accept the new anti-torque devices becomes evident. It was assumed that the existing installed engine power of the baseline vehicle remains unchanged, and, therefore, increased power demands to operate the new anti-torque device(s) influence the hover capability of the aircraft, in terms of reduced gross weight. On the other hand, the "New Design" configurations are based on the same gross weight as the Model 286, namely 4700 pounds. The increased power required for the new anti-torque devices is reflected principally in higher propulsion system weight. These weights were used for payload-range comparisons.

The influence of adding the new anti-torque system(s) to the aircraft is shown in detail for every component listed in the table. Those components whose weights are not influenced by the changes remain constant across the various columns. The estimated amounts of changes, or additions or deletions of weight components, can also be identified by comparing across the various columns. All changes pertain to the addition of either of the two new anti-torque systems.

TABLE III. WEIGHT COMPARISON SUMMARY

	Model				
	<u>286</u>	<u>Modified 286</u>		<u>New Design</u>	
	Tail Rotor	Fan-In-Fin	Internal Fan	Fan-In-Fin	Internal Fan
Main Rotor	726	726	726	726	726
Tail Rotor/Fan-in-Fin	29	15		15	
Internal Fan Installation			97		86
Stabilizer	15	17	17	17	17
Fin	43	50	36	50	31
Fuselage	496	496	528	496	522
Landing Gear	141	141	141	141	141
Flight Controls	327	336	336	336	336
Propulsion	455	455	455	478	474
Main Gearbox and Lub. System	335	335	335	335	335
Intermediate Gearbox	20	20		20	
Aft Gearbox	35	26		26	
Shaft; Engine to Main Gearbox	8	8	8	8	8
Shaft; Main Gearbox to Tail	42	45		45	
Shaft; Main Gearbox to Fan			20		20
Pulleys and Belt			16		
Instruments	58	60	60	60	60
Hydraulics	38	40	40	40	40
Electrical, Comm., Furn., etc.	<u>230</u>	<u>230</u>	<u>230</u>	<u>230</u>	<u>230</u>
EMPTY WEIGHT	2998	3000	3045	3023	3026
Pilot	170	170	170	170	170
Trapped Fuel and Oil	19	19	19	19	19
Engine Oil	<u>18</u>	<u>18</u>	<u>18</u>	<u>18</u>	<u>18</u>
OPERATING WEIGHT	3205	3207	3252	3230	3233
Payload	<u>375</u>	<u>733</u>	<u>728</u>	<u>950</u>	<u>947</u>
ZERO FUEL WEIGHT	4180	3940	3980	4180	4180
Full Fuel	<u>520</u>	<u>520</u>	<u>520</u>	<u>520</u>	<u>520</u>
GROSS WEIGHT	4700	4460	4500	4700	4700

All values are in pounds.

6. PERFORMANCE DATA

BASIC YAW REQUIREMENTS

Since the Lockheed Model 286 has been FAA certificated, its flying and ground handling yaw control is satisfactory. The lateral yawing thrusts required by Specification MIL-H-8501A were met by the existing tail rotor and will be met by the selected new yaw control devices. The lateral yawing thrust required is that necessary to balance the main rotor torque plus that necessary for side-wind trim plus an additional amount for yaw control. The applicable paragraphs of MIL-H-8501A are 3.3.5 and 3.3.6.

Paragraph 3.3.5 specifies:

"Directional control power shall be such that when the helicopter is hovering in still air at the maximum overload gross weight or at rated takeoff power, a rapid 1.0-inch step displacement from trim of the directional control shall produce a yaw displacement at the end of 1.0 second which is at least

$$\frac{110}{\sqrt[3]{W + 1000}}$$

degrees. When maximum available displacement from trim of the directional control is rapidly applied at the conditions specified above, the yaw angular displacement at the end of 1.0 second shall be at least

$$\frac{330}{\sqrt[3]{W + 1000}}$$

degrees. In both equations, W represents the maximum overload gross weight of the helicopter in pounds."

In analyses made to examine capability to meet these requirements, the "maximum overload gross weight" is made 4700 pounds, the maximum gross weight for which the Model 286 was FAA certificated. Control linkage details are assumed to be such that full pedal thrust is adequate and 1.0-inch pedal thrust will generate at least one-third as much thrust as required.

Paragraph 3.3.6 of MIL-H-8501A specifies:

"It shall be possible to execute a complete turn in each direction while hovering over a given spot at the maximum overload gross weight or at take-off power (in and out of ground effect), in a wind of at least 35 knots. To insure adequate margin of control during these maneuvers, sufficient control shall remain at the most critical azimuth angle relative to the

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wind, in order that, when starting at zero yawing velocity at this angle, the rapid application of full directional control in the critical direction results in a corresponding yaw displacement of at least

$$\frac{110}{\sqrt[3]{W + 1000}}$$

degrees in the first second, where W represents the maximum overload gross weight of the helicopter in pounds."

The same gross weight of 4700 pounds that is used in the prior section will also be used here.

DIMENSIONS

Pertinent dimensions of the aircraft used in the analysis are as follows:

	<u>Tail Rotor</u>	<u>Fan-in-Fin</u>	<u>Internal Fan</u>
Diameter, ft	6.5	2.5	2.5
Number of Blades	2	11	11
Chord (constant), in.	7.80	2.00	2.00
Solidity $\left(\frac{bc}{\pi R}\right)$.1273	.466	.466
⌘ Main Rotor to ⌘ Yaw Device, ft	21.79	21.79	21.79
Fin Area, sq ft	11.2	15.9	15.9
Tip Speed, ft/sec	713	713	713

YAW THRUST FOR MAIN ROTOR COUNTER-TORQUE

Model 286 Hovering Performance

The hovering performance of the Lockheed Model 286 is presented in Figure 20 (a reproduction of Figure 21 of Lockheed Report LR 19906*). A line showing OGE hovering is added to the figure.

*

W. P. Groth, F. P. Lentine, and R. E. Sadowski, MODEL 286 FAA CERTIFICATION REPORT, Lockheed Report LR 19906, July 1966.

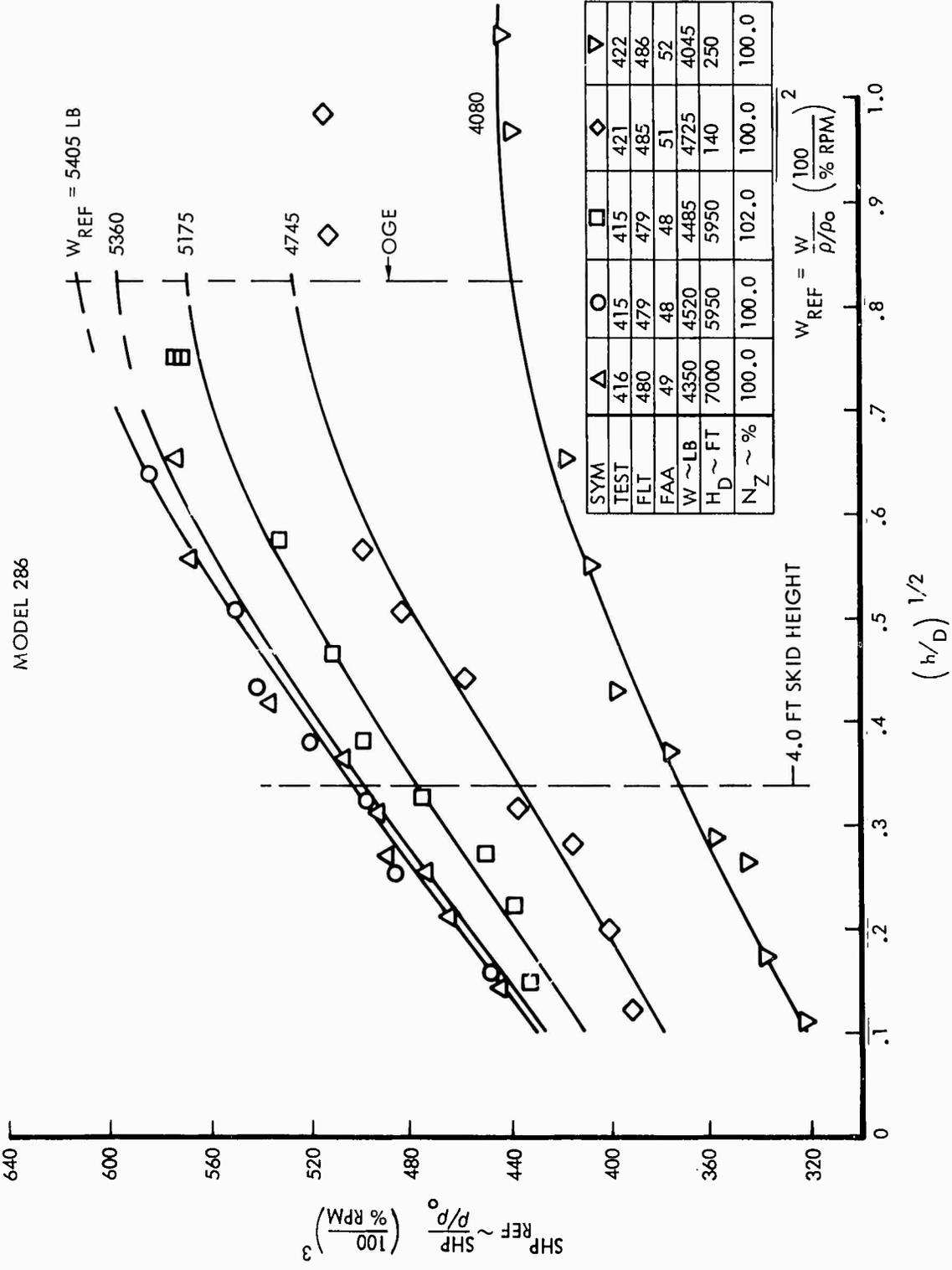


Figure 20. SHP vs. Skid Height.

Figure 21 is constructed from Figure 20. From Figure 21, the engine SHP at 4700 pounds gross weight, OGE, is shown to be 515.

Model 286 Installation and Accessory Losses

The installation and accessory losses are presented in Figure 22 (a reproduction of Figure 80 of Lockheed Report LR 19906.)* From this figure, an expression used to determine power losses at sea level, in standard air, is

$$\begin{aligned} \text{SHP}_{\text{Losses}} &= 37.0 + .0158 (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}} - 300) \\ &= 32.2 + .0158 (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}}) \end{aligned}$$

Using engine SHP of 515 as noted above,

$$\begin{aligned} 515 &= 32.2 + 1.0158 (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}}) \\ \text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}} &= 475.3 \end{aligned}$$

from which the installation and accessory losses are

$$515 - 475.3 = 39.7 \text{ SHP}$$

Tail Rotor Thrust for Main Rotor Counter-Torque

The calculations summarized in Table IV show a tail rotor thrust of 299 pounds.

YAW CONTROL THRUST

The yaw displacement at the end of 1.0 second, as required by MIL-H-8501A, Paragraph 3.3.5 (see specification quote, page 67), is

$$\psi = \frac{330}{\sqrt[3]{5700}} = \frac{330}{17.86} = 18.48 \text{ deg}$$

The lateral yawing thrust required to yaw the helicopter the specified amount in 1 second is

$$F_{\text{TR}} l_{\text{TR}} = J_{\psi} \frac{2\psi}{t^2}$$

* W. P. Groth, F. P. Lentine, and R. E. Sadowski, MODEL 286 FAA CERTIFICATION REPORT, Lockheed Report LR 19906, July 1966.

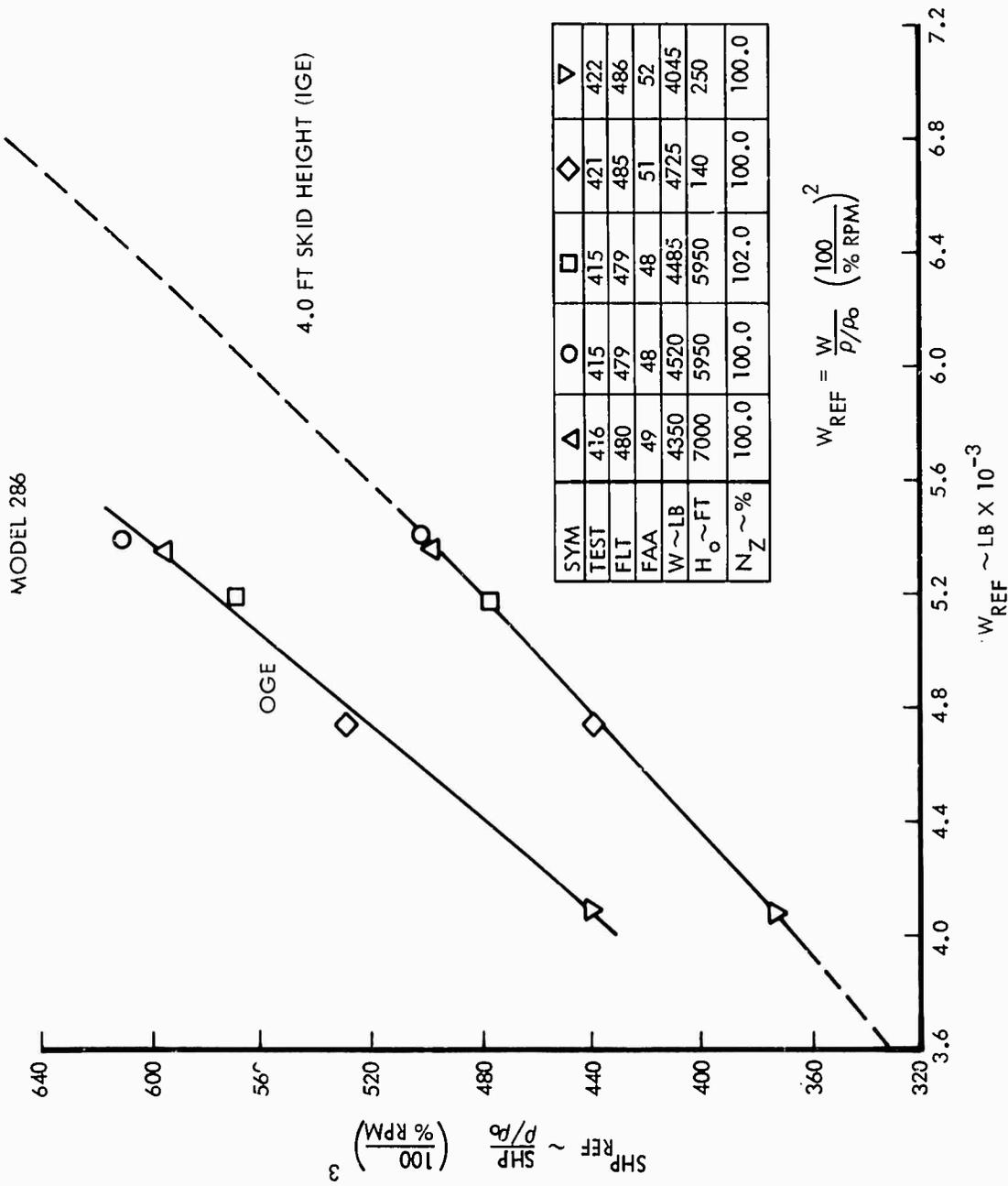


Figure 21. SHP vs. Gross Weight.

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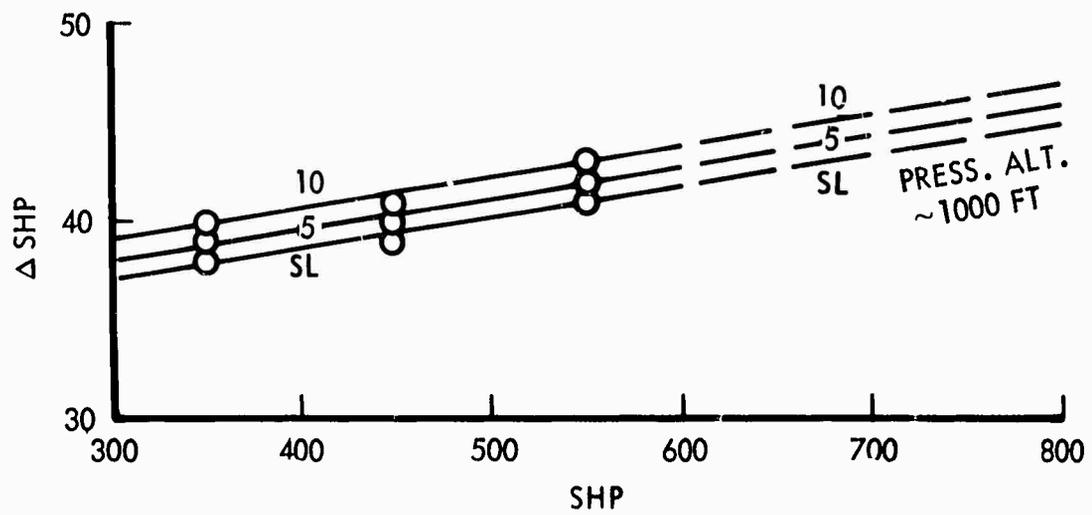
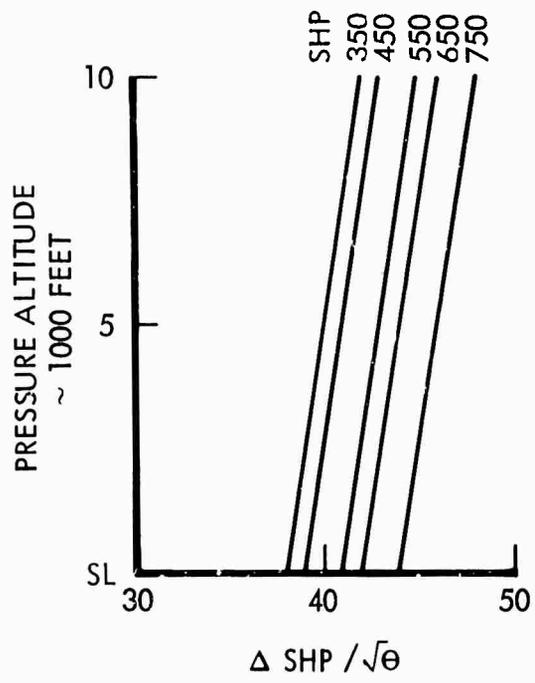


Figure 22. Installation and Accessory Losses.

Therefore, for the Lockheed Model 286, which has a yaw inertia (less main rotor) of 3330 slug-ft²,

$$21.79 T_{TR} = 3330 \times \frac{2 (18.48/57.29)}{1.0^2}$$

$$T_{TR} = 99 \text{ lb}$$

SIDE-WIND YAW THRUST

From the quoted paragraphs of MIL-H-8501A, the lateral thrust requirement to provide for yaw control in a 35-knot side wind is

$$T_{TR} = 99 \times \frac{110}{330} = 33 \text{ lb}$$

The concurrent lateral thrust required to overcome a 35-knot side wind during hover is shown in Table V to be 53 lb. Thus, the total lateral thrust required is

$$33 + 53 = 86 \text{ lb}$$

This requirement is less than calculated in the preceding paragraph and therefore will not prevail.

MAXIMUM YAW THRUST

The yaw thrust required is the sum of the yaw thrusts calculated to counter the main rotor torque plus that to provide yaw control,

$$T_{TR} = 299 + 99 = 398 \text{ lb}$$

The internal fan and the fan-in-fin concepts will each be required to generate this 398 pounds of lateral thrust at sea level in standard air.

YAW DEVICE POWER REQUIRED

Required power is determined for flight at sea level at standard temperature. The required yaw thrust determined in the preceding paragraph is 398 pounds. The helicopter total power required, as shown in a preceding paragraph, is 515 SHP; the installation plus accessory losses have been shown to be 39.7 SHP, so that $SHP_{MR} + SHP_{TR}$ is 475.3 SHP.

Tail Rotor Power Required

The tail rotor power required to hover at 4700 pounds gross weight at sea level in standard air was shown to be 34.8 SHP (Table IV). This is 6.8% of the total SHP and 7.9% of SHP_{MR} .

TABLE IV. TAIL ROTOR ANTI-TORQUE THRUST

Sea Level, Standard Air Hovering	Gross Weight = 4700 lb		
	Trial #1	Trial #2	Final Result (g)
1. $\text{SHP}_{\text{TR}} / (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}})$	10%	7%	7.32%
2. SHP_{TR}	47.53	32.37	34.8
3. SHP_{MR}	427.8	442.0	440.5
4. Q_{MR} ft-lb (a)	6336	6546	6524
5. $T_{\text{TR}} = (4)/21.79$ lb	290.8	300.4	299.2
6. $C_T = (5)/40094$ (b)	.00725	.00749	.00746
7. $\bar{c}_l = \frac{6C_T}{B^3\sigma}$ (c)	.413	.426	.425
8. δ (d)	.0102	.0106	.0105
9. $v^2 = (5)/.1577$ (e)	1842	1903	1897
10. v	42.9	43.6	43.5
11. $\text{SHP}_i = 1.10 \frac{(5)(10)}{550}$	24.9	26.2	26.1
12. $\text{SHP}_o = 825 \delta$ (f)	8.4	8.7	8.7
13. $\text{SHP}_{\text{TR}} = (11) + (12)$	33.3	34.9	34.8

NOTES

(a) $550 \text{ SHP}_{\text{MR}} = Q_{\text{MR}} \Omega = Q_{\text{MR}} \Omega \frac{R}{R} = Q_{\text{MR}} \frac{650}{17.5} = 37.143 Q_{\text{MR}}$

(b) $(\pi R^2) \rho (\Omega R)^2 = 33.18 \times .002377 \times 713^2 = 40094$

(c) $\bar{c}_l = \frac{6 C_T}{.943 \times .1273} = 56.9 C_T$

(d) Figure 23

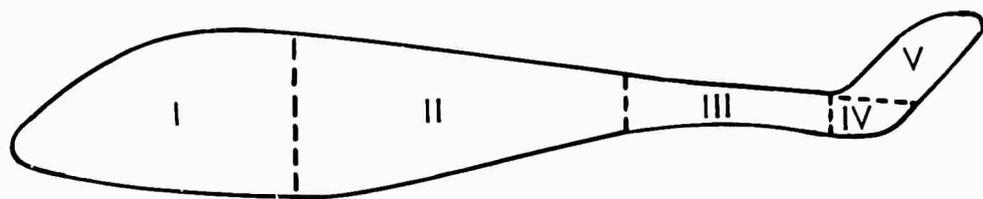
(e) $v^2 = \frac{T/A}{2 \rho} = \frac{T/33.18}{.004754} = \frac{T}{.1577}$

(f) $\text{SHP}_o = \frac{\delta \rho \sigma}{4400} (\pi R^2) \Omega R^3$
 $= \frac{.002377 \times .1273 \times 33.18 \times 713^3}{4400}$
 $= 825 \delta$

(g) For (2) = (13) by plotting (2) vs (13)

TABLE V. TAIL ROTOR TRUST TO TRIM
 LOCKHEED MODEL 286 IN 35-KNOT SIDE WIND

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Segment	Lateral Projected Area (sq ft)	C_D	Drag at 35 kn (ft)	Yawing Moment Arm (ft)	Yawing Moment (4)x(5) (ft-lb)	Lateral Thrust Required (lb)
I	39.7	.40	65.5	-4.0	-262	
II	38.5	.40	63.5	4.5	245	
III	8.8	.40	14.5	14.2	206	
IV	2.6	1.00	10.7	18.9	202	
V	9.1	1.00	36.5	20.8	760	
TOTAL				21.79	1151	53



The thrust/horsepower of the tail rotor is $299/34.8 = 8.4$ lb/SHP.

When the control load of 99 pounds is added, the tail rotor induced SHP increases from 26.1 to 40.0 and the profile SHP increases from 8.7 to 14.9. The total tail rotor SHP increases from 34.8 to 54.9 and the thrust/horsepower decreases from 8.4 to 7.3. The helicopter total SHP (main rotor, tail rotor and losses) increases from 515 to 535.

While it is not a MIL-H-8501A requirement, it is possible to operate at the full power of the engine simply by increasing the rate of climb. Since only 15 SHP (550 less 535) additional are available, and the \bar{c}_l is only .566* when hovering and generating the 99 pounds control load, it is clear that the $c_{l \max}$ of .82 (Figure 23) will not be exceeded.

Fan-in-Fin Power Required

The solidity of the fan permits the blade sections to operate at a c_l near maximum c_l/c_d (minimum power for a fixed fan thrust) when the fan generates the yaw thrust required to balance the main rotor torque, 299 pounds. On occasions when the fan will also generate the control force of 99 pounds, the \bar{c}_l must be higher but will still be less than $c_{l \max}$.

From Figure 24, maximum c_l/c_d occurs at 5.2 degrees angle of attack. From Figure 22, at this angle of attack,

$$c_l = .657$$

$$c_d = .0118$$

The fan-in-fin \bar{c}_l was preliminarily considered to be at these values when generating the 299 pounds of main rotor counter-torque thrust.

Since $\bar{c}_l = 6 C_T (B^3 - X_o^3) \sigma$, by fixing \bar{c}_l and C_T , σ and, hence, the blade chord can be determined. In fixing C_T for the fan, note that the shroud of the fan-in-fin generates 40 percent as much thrust as the fan. Therefore, the fan thrust is

$$T_{\text{Fan}} = \frac{.299}{1.40} = 214 \text{ lb}$$

$$*(.425 \text{ from Table IV}) \times \frac{398}{299} = .566$$

TAIL ROTOR AND FENESTRON

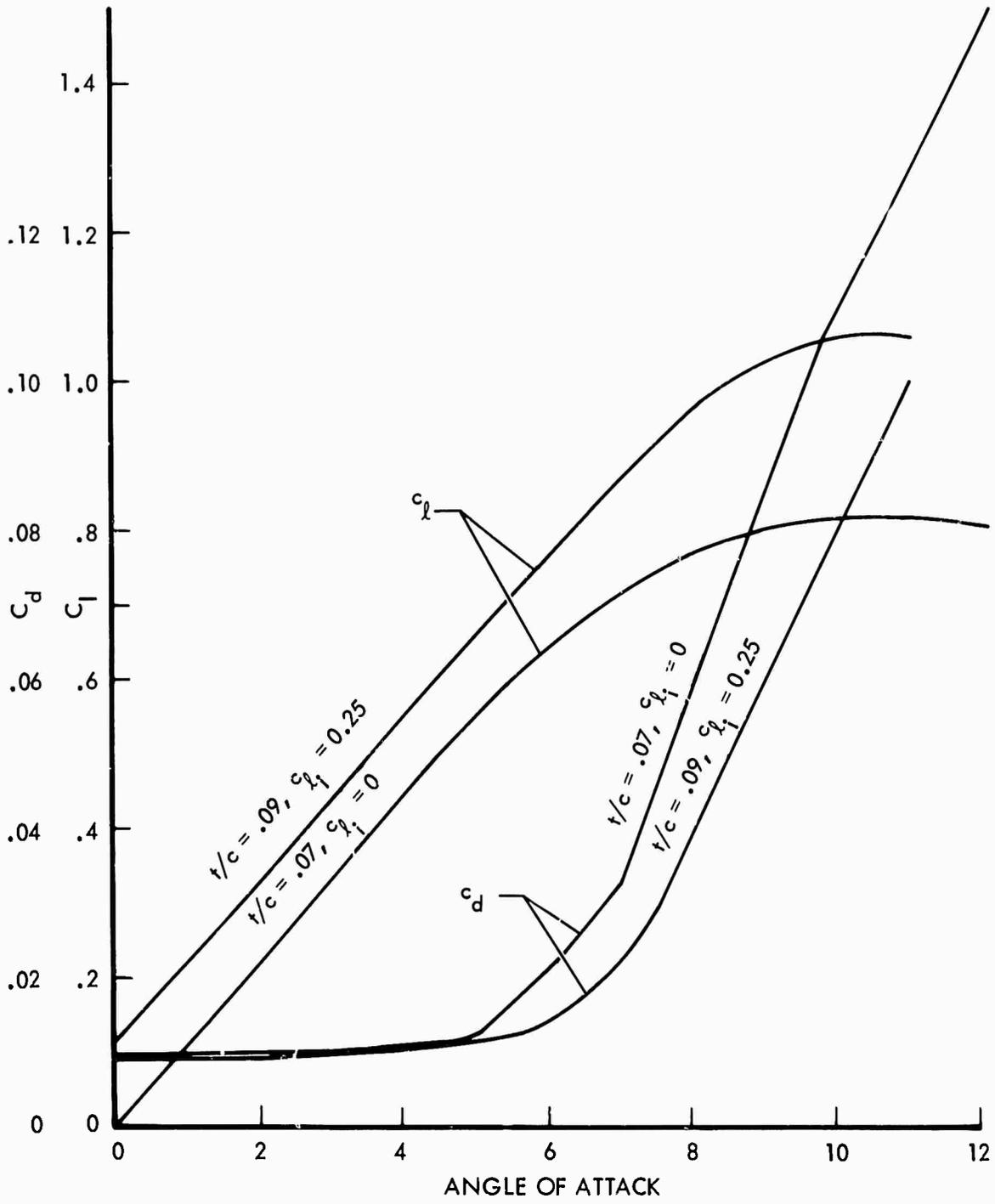


Figure 23. Airfoil Section Aerodynamic Characteristics.

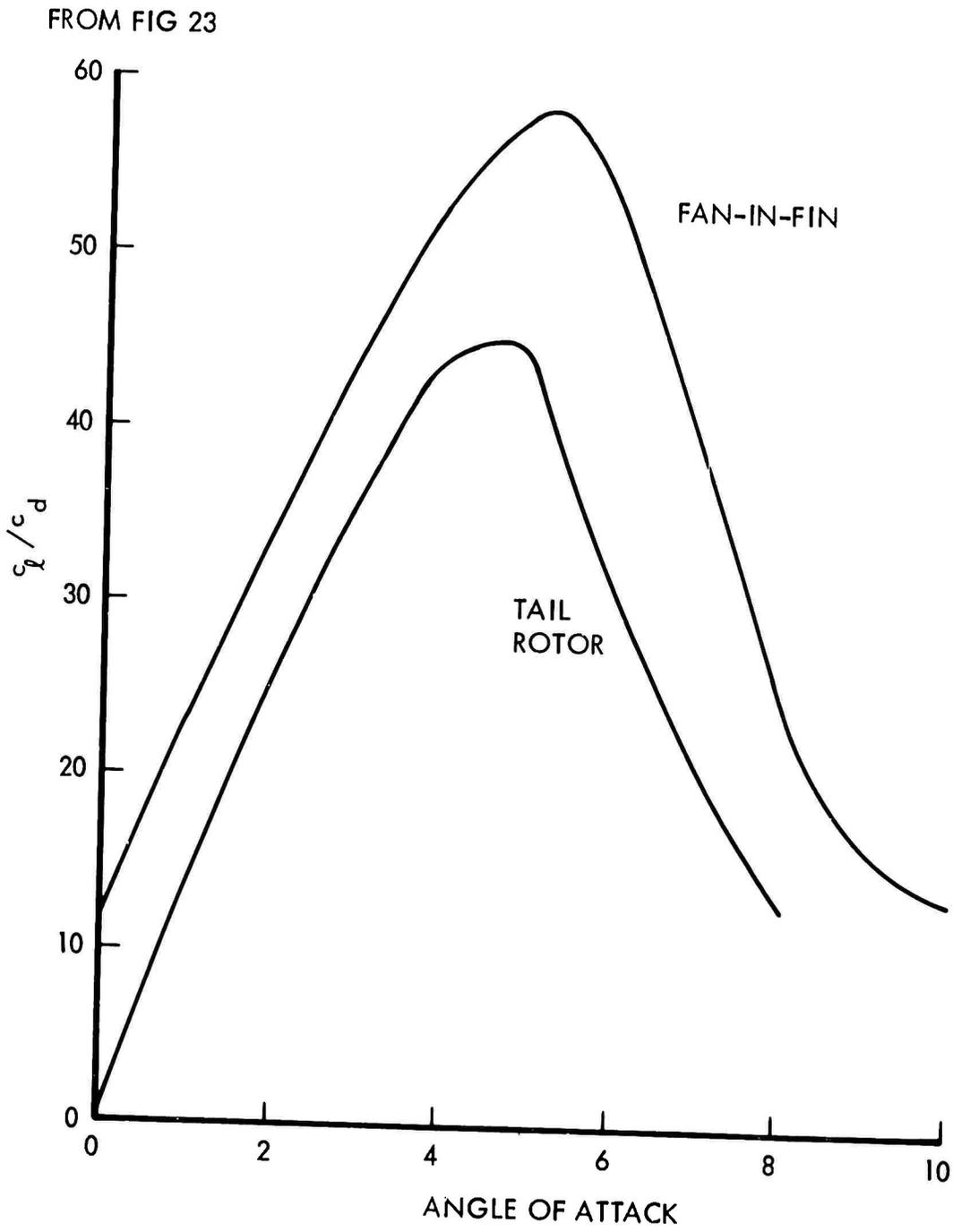


Figure 24. Airfoil Section c_l/c_d .

and

$$C_T = \frac{.214/4.909}{.002377 \times 713^2} = \frac{43.6}{1204} = .0361$$

$$\bar{c}_l = \frac{6C_T}{(B^3 - X_0^3)\sigma}$$

$$.675 = \frac{6 \times .0361}{(.99^3 - .37^3)\sigma}$$

$$\sigma = \frac{.2166}{.620} = .350$$

$$bc = .285 \times \pi \times 1.25 = 1.375 \text{ ft}$$

$$= 16.50 \text{ in.}$$

If $b = 11$ then $c = 1.50$ in.

At the maximum thrust of 398 pounds, the \bar{c}_l is $.675(398/299) = .897$. This is less than the $c_{l \text{ max}}$ of 1.065 shown in Figure 23 and therefore will be satisfactory.

However, recognizing operational problems of yaw control that have been experienced with tail rotors designed by these elemental considerations, the blade chord is arbitrarily increased from 1.50 to 2.00 inches. Power required and fuel consumed will be based on eleven blades of 2.00 inch chord.

$$\sigma = \frac{11(2/12)}{3.1416 \times 1.25} = .466$$

For a fan-in-fin generating static thrust, test data indicate that the shroud generates 40 percent as much thrust as the fan. Let the induced velocity be v at the fan and nv at the shroud exit, as shown in Figure 25. Since $n = 2$ for an unshrouded propeller (shroud thrust = 0) and $n = 1$ for a "full" shroud where the shroud thrust equals the fan thrust, the value of n for the fan-in-fin lies between 1 and 2.

The power required to accelerate the fan-in-fin slipstream is

$$550 \text{ SHP}_{\text{F\&F ind}} = T_{\text{F\&F}} \frac{nv_{\text{Fan}}}{2} = 1.40 T_{\text{Fan}} \frac{nv_{\text{Fan}}}{2}$$

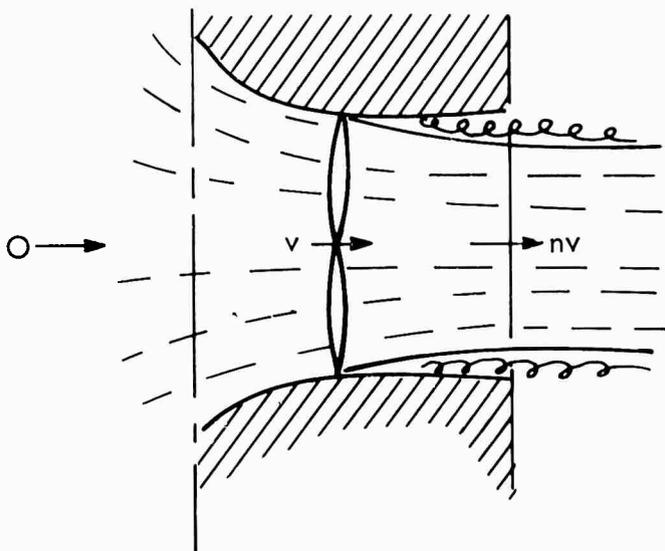


Figure 25. Fan-in-Fin Induced Flow.

This same power is also, allowing a 5 percent power loss due to nonuniformity of slipstream velocity,

$$550 \text{ SHP}_{\text{F\&F}_{\text{ind}}} = T_{\text{Fan}} v_{\text{Fan}}$$

Equating,

$$1.40 T_{\text{Fan}} \frac{nv_{\text{Fan}}}{2} = 1.05 T_{\text{Fan}} v_{\text{Fan}}$$

$$n = 2.10/1.40 = 1.50$$

Having stipulated that the shroud (fin) generated 40 percent as much thrust as the fan, it follows that $n = 1.50$, and that the exit slipstream has an area two-thirds (i.e., $1.0/1.5$) as large as the fan. Although the shroud is shown as a constant-area cylinder, the slipstream experiences the two-thirds reduction in the cross-sectional area. Thus, the slipstream exit area equals $(2/3) \times 4.909 = 3.273$ sq ft.

The significance of this exit area is that it is less than the exit area of the louvered exit of the internal fan. The internal fan thus has less induced power for the same lateral yawing thrust.

$$T_{\text{F\&F}} = A_{\rho} v_{\text{Fan}} (1.50 v_{\text{Fan}}) = 1.50 A_{\rho} v_{\text{Fan}}^2$$

For the 299 pounds of main rotor counter-torque yaw thrust,

$$v_{\text{Fan}}^2 = \frac{299/4.909}{1.50 \times .002377} = \frac{61.0}{.003566} = 17100$$

$$v_{\text{Fan}} = 130.4 \text{ ft/sec}$$

$$550 \text{ SHP}_{\text{F\&F}_{\text{ind}}} = 1.05 \times 299 \times 1.50 \times 130.4/2 = 30800 \text{ ft-lb/sec}$$

$$\text{SHP}_{\text{F\&F}_{\text{ind}}} = 56.1$$

Fan-in-Fin Profile SHP

$$\bar{c}_l = \frac{6 \times .0361}{(.99^3 - .37^3) \times .466} = .507$$

so, from Figure 23,

$$\delta = .0100$$

$$\text{SHP}_{\text{F/F}_{\text{prof}}} = .0100 \frac{.002377 \times .466 \times 4.909 \times 713^3}{4400}$$

$$\text{SHP}_{\text{F/F}_{\text{prof}}} = 4.5$$

Fan-in-Fin Total SHP

$$\text{SHP}_{\text{F/F}} = \text{SHP}_{\text{F\&F}_{\text{ind}}} + \text{SHP}_{\text{F/F}_{\text{prof}}}$$

$$\text{SHP}_{\text{F/F}} = 56.1 + 4.5 = 60.6$$

Helicopter Total SHP

$$\text{SHP}_{\text{losses}} = 32.2 + .0158 (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}})$$

So, for the fan-in-fin, with $\text{SHP}_{\text{MR}} = 440.5$ from Table IV,

$$\begin{aligned} \text{SHP}_{\text{losses}} &= 32.2 + .0158 (440.5 + 60.6) \\ &= 32.2 + 7.9 = 40.1 \end{aligned}$$

$$\text{SHP}_{\text{total}} = 440.5 + 40.1 + 60.6 = 541$$

Percentages

The fan-in-fin SHP is thus 11.2 percent of the total SHP, which is 4.4 percent more than the tail rotor. It is 13.7 percent of the SHP_{MR} , which is 5.8 percent more than the tail rotor.

Thrust Horsepower

The thrust/horsepower of the fan-in-fin is $299/60.6 = 4.9$ lb/SHP.

With Control Load Added

When the control load of 99 pounds is added, the fan-in-fin induced SHP increases from 56.1 to 86.0 and the profile SHP increases from 4.5 to 5.3. Thus, the total fan-in-fin SHF increases from 60.6 to 91.3 and the thrust/horsepower decreases from 4.9 to 4.4. The total fan-in-fin SHP increases from 541 to 573. This is 22 SHP more than the 5-minute rating of the engine.

Internal Fan Power Required

This system uses the fan-in-fin fan, relocated to produce the internal-fan configuration. The louvered exit area (20 in. high and 30 in. long) is 4.16 square feet.

The power expended in this system is assumed to be composed of:

- o Induced power in an airstream which has a final cross sectional area equal to that of the louvered exit.
- o The profile power of the fan-in-fin fan.
- o An additional 10 percent to account for inlet, duct, slipstream rotation and turning vane losses.

Internal-Fan Induced SHP

$$\begin{aligned} \text{Louver Thrust} &= A_{\text{Louv}} \rho v_{\text{Louv}}^2 \\ 299 &= 4.16 \times .002377 \times v_{\text{Louv}}^2 \\ v_{\text{Louv}}^2 &= 30300 \\ v_{\text{Louv}} &= 173.8 \text{ ft/sec} \end{aligned}$$

$$\begin{aligned}
550 \text{ SHP}_{\text{IF}_{\text{ind}}} &= 1/2 (A_{\text{Louv}} \rho v_{\text{Louv}}) \times v_{\text{Louv}}^2 \\
&= 1/2 (4.16 \times .002377 \times 173.8^3) \\
\text{SHP}_{\text{IF}_{\text{ind}}} &= 47.2
\end{aligned}$$

Internal-Fan Profile SHP

Same as fan-in-fin = 4.5 SHP

Internal-Fan Duct and Turning Vane Loss

$$\text{SHP}_{\text{IF}_{\text{duct}}} = .10 (47.2 + 4.5) = 5.2 \text{ SHP}$$

Internal-Fan Total SHP

$$\begin{aligned}
\text{SHP}_{\text{IF}} &= \text{SHP}_{\text{IF}_{\text{ind}}} + \text{SHP}_{\text{IF}_{\text{prof}}} + \text{SHP}_{\text{IF}_{\text{duct}}} \\
&= 47.2 + 4.5 + 5.2 = 56.9
\end{aligned}$$

Helicopter Total SHP

$$\begin{aligned}
\text{SHP}_{\text{Losses}} &= 32.2 + .0158 (\text{SHP}_{\text{MR}} + \text{SHP}_{\text{TR}}) \\
&= 32.2 + .0158 (440.5 + 56.9) \\
&= 32.2 + 7.9 = 39.9 \\
\text{SHP}_{\text{Total}} &= 440.5 + 39.9 + 56.9 = 537
\end{aligned}$$

Percentages

The internal fan SHP is thus 10.6 percent of the total SHP, which is 3.8 percent more than the tail rotor and 0.6 percent less than the fan-in-fin. It is 12.9 percent of the SHP_{MR} , which is 5.0 percent more than the tail rotor and 0.8 percent less than the fan-in-fin.

Thrust/Horsepower

The thrust/horsepower of the internal fan is $299/56.9 = 5.3 \text{ lb/SHP}$.

With Control Load Added

When the control load of 99 pounds is added, the internal fan induced SHP increases from 47.2 to 72.3, the profile power increases from 4.5 to 5.3, and the duct loss increases from 5.2 to 7.8. Thus, the total internal fan SHP increases from 56.9 to 85.4 and the thrust/horsepower decreases from 5.3 to 4.7. The total internal fan SHP increases from 537 to 566. This is 16 SHP more than the 5-minute rating of the engine.

FORWARD FLIGHT POWER REQUIRED AND AVAILABLE

A digital program was used to compute the SHP_{MR} , T_{TR} and T_{Fin} .

Credibility of the results is established by matching two Model 286 flight test speed-power polars as shown in Figure 26. From a run of this program at a gross weight of 4700 pounds, at sea level, at standard temperature air, SHP_{MR} , SHP_{TR} , T_{TR} , and T_{Fin} were determined. SHP_{MR} is presented in Figure 27, T_{TR} and T_{Fin} in Figure 28, and SHP_{TR} in Figure 29.

The area of the Model 286 helicopter fin is 11.7 square feet. At the gross weight of 4700 pounds, when flying at sea level in standard temperature air at 140 knots true airspeed, the fin supplies all the main rotor counter-torque force (T_{CT}). The fin is then acting at a lift coefficient of .467 to generate 364 pounds of lateral yawing force (Figure 27). Since this lift coefficient will remain the same at all speeds, the lateral fin force (T_{Fin}) is $364 (V/140)^2$ and T_{TR} is $T_{CT} - T_{Fin}$.

When the tail rotor is replaced by the internal fan or the fan-in-fin, the yaw stabilizing effect of the tail rotor must be replaced by additional fin area (from 11.7 to 15.9 square feet). However, if the lift coefficient of this larger fin is reduced proportionately, as considered here, then the fin force remains the same as with the smaller fin, at all airspeeds. These lateral forces are presented in Figure 27.

The difference in speed-power polars between the Model 286 with the tail rotor, internal fan or fan-in-fin is composed of two parts: the difference in the power required to generate this T_{TR} force, and the difference in the parasite power due to the difference in equivalent flat plate area resulting from the trim change associated with using the internal fan for a propulsive unit.

The final result of adjustments to power required is presented in Figure 30 .

The power available has been increased for the internal fan and the fan-in-fin by 22 SHP and 26 SHP respectively. These are the increments required to maintain the same vertical flight performance at 4700 pounds gross weight, at sea level, in standard air.

MODEL 286

SHIP: S/N 2001

4 JUNE 66

LANDING GEAR RETRACTED

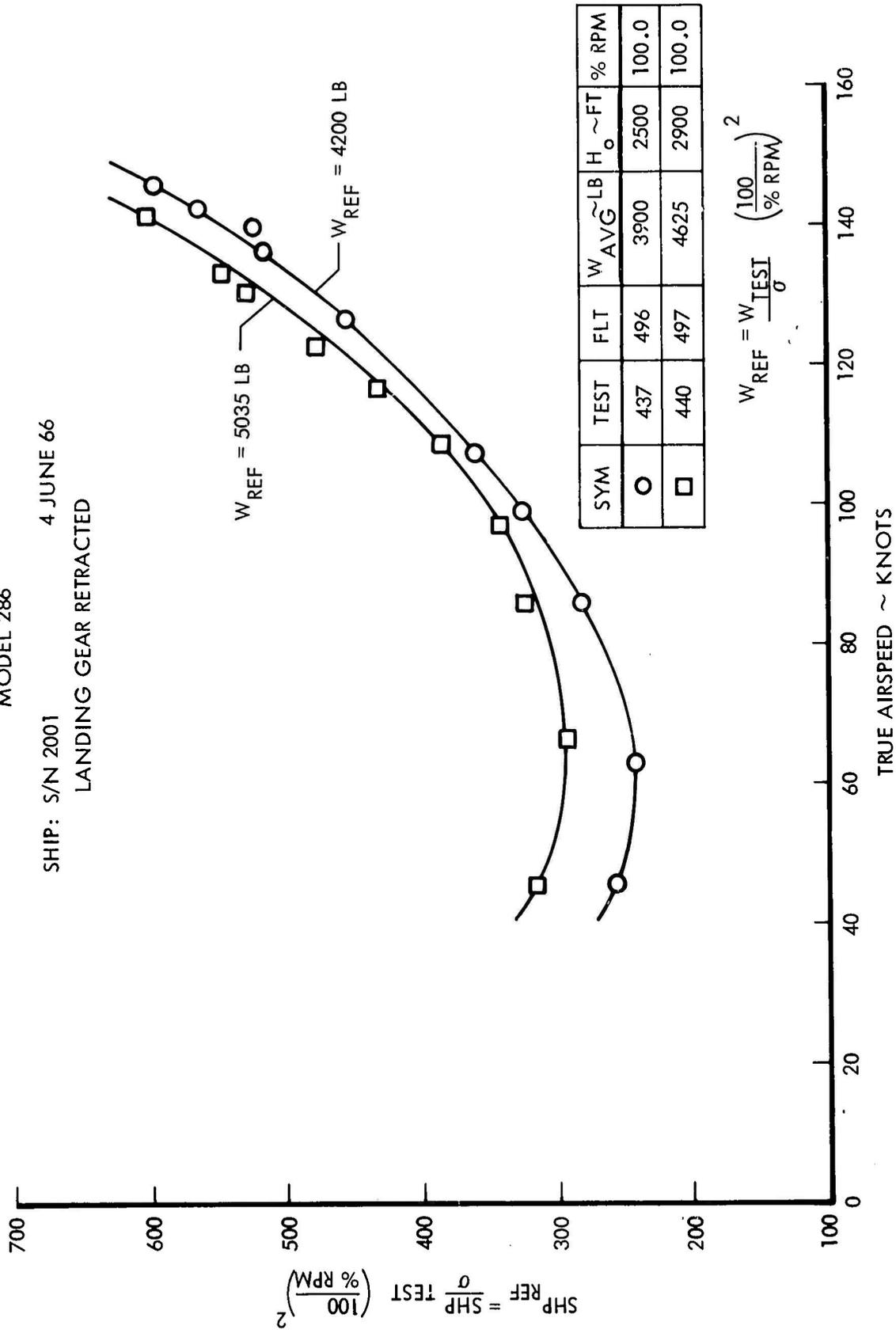


Figure 26. Level Flight Performance.

LOCKHEED MODEL 286

GROSS WT = 4700 LB

S.L. STD. CONDITIONS

$f_o = 9.5$ SQ FT

ANTI-TORQUE THRUST = $T_{TR} + T_{FIN}$

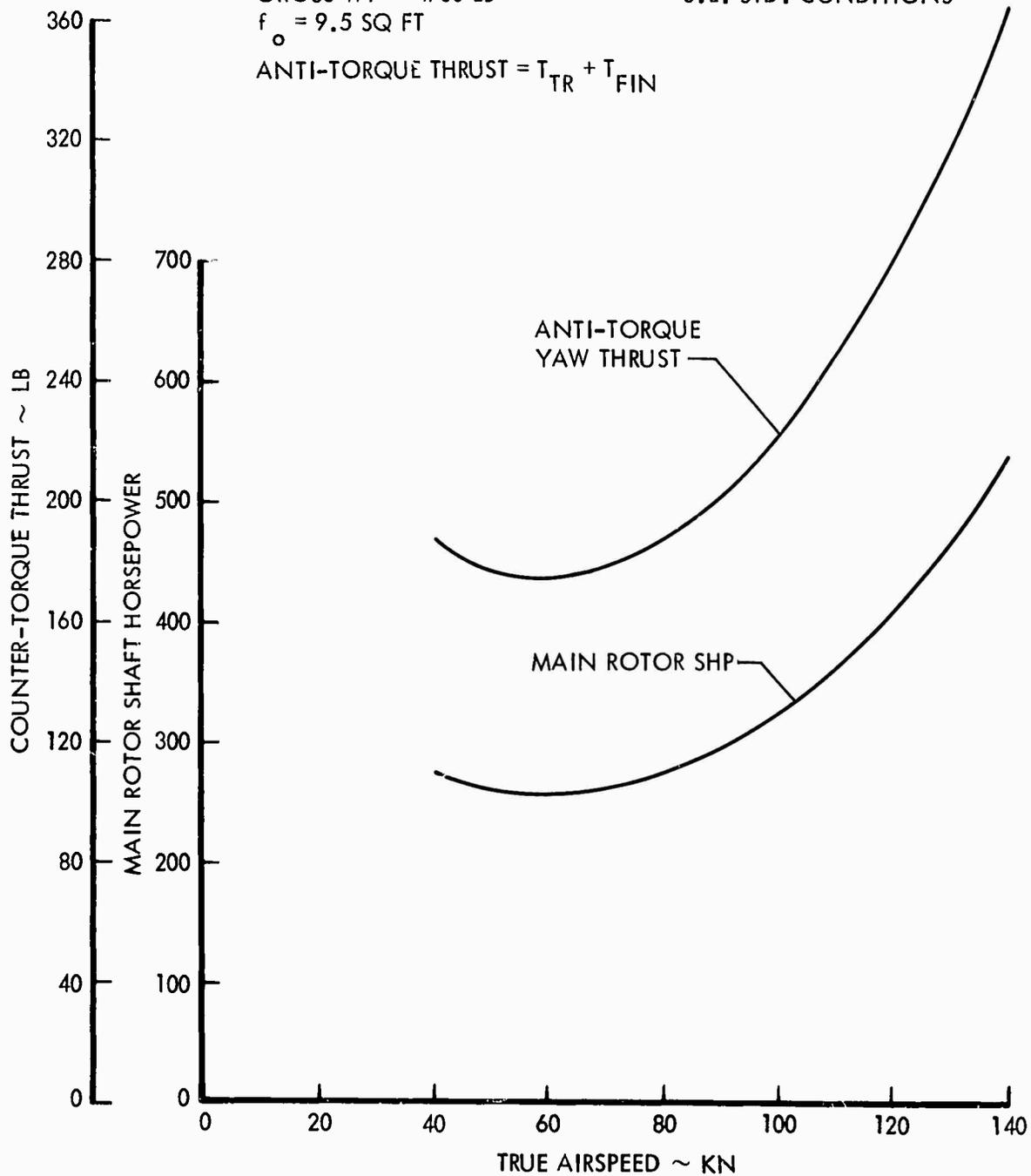


Figure 27. Main Rotor SHP and Anti-Torque Thrust vs. TAS.

GROSS WT = 4700 LB
 $f_o = 9.5$ SQ FT

S.L. STD. CONDITIONS

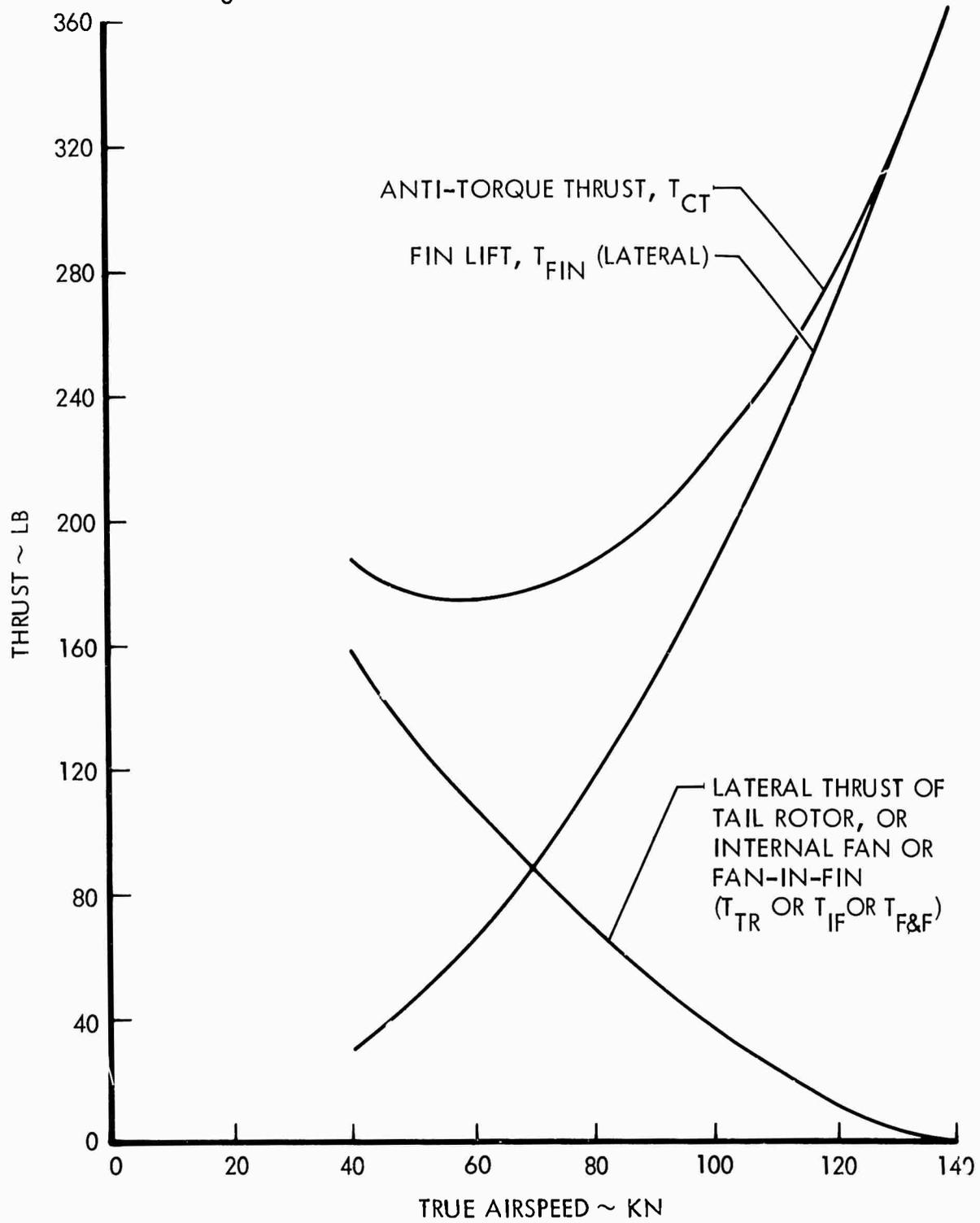


Figure 28. Anti-torque Thrust vs. TAS.

LOCKHEED MODEL 286
GROSS WT = 4700 LB S.L. STD CONDITIONS

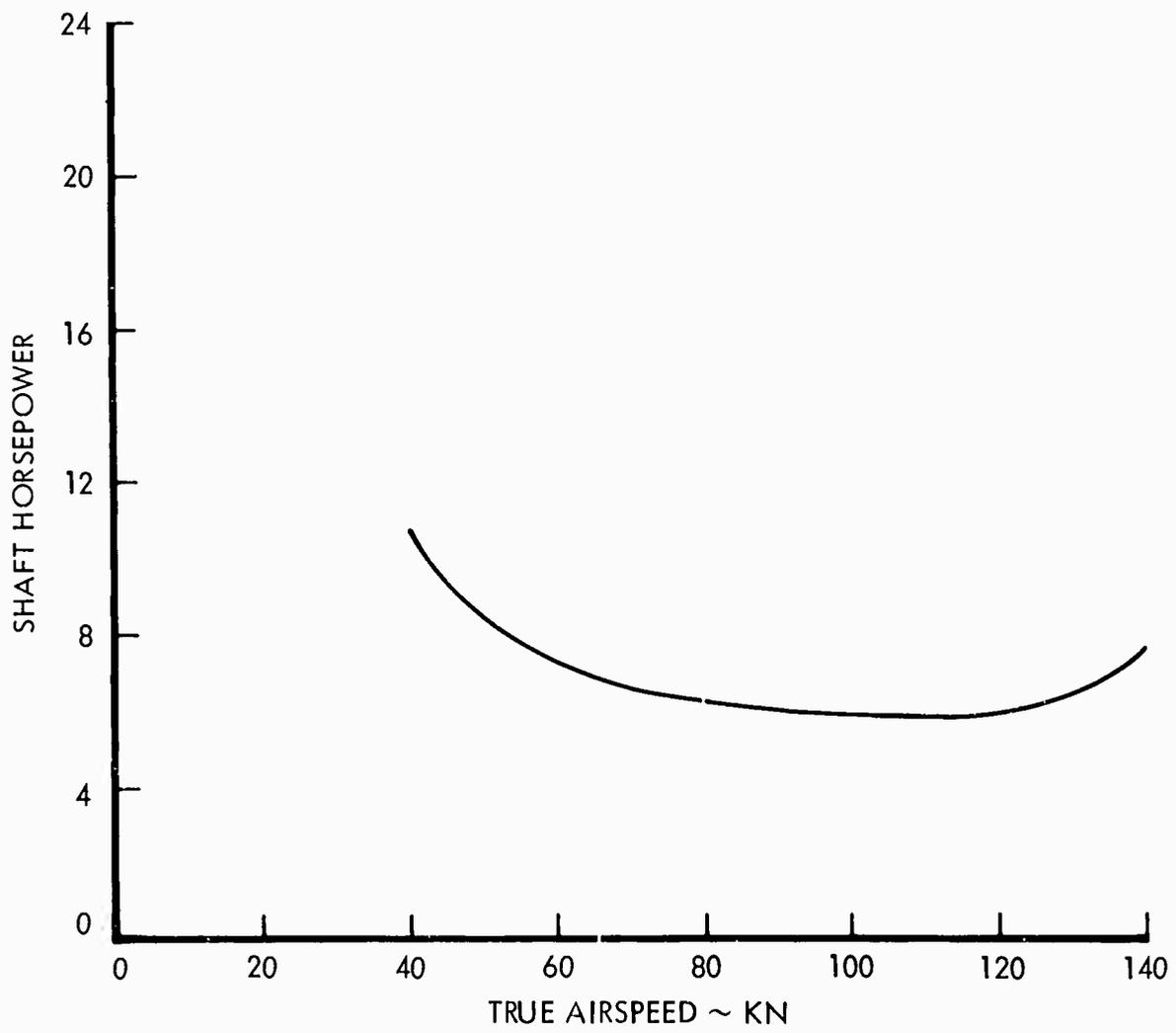


Figure 29. Tail Rotor SHP vs. TAS.

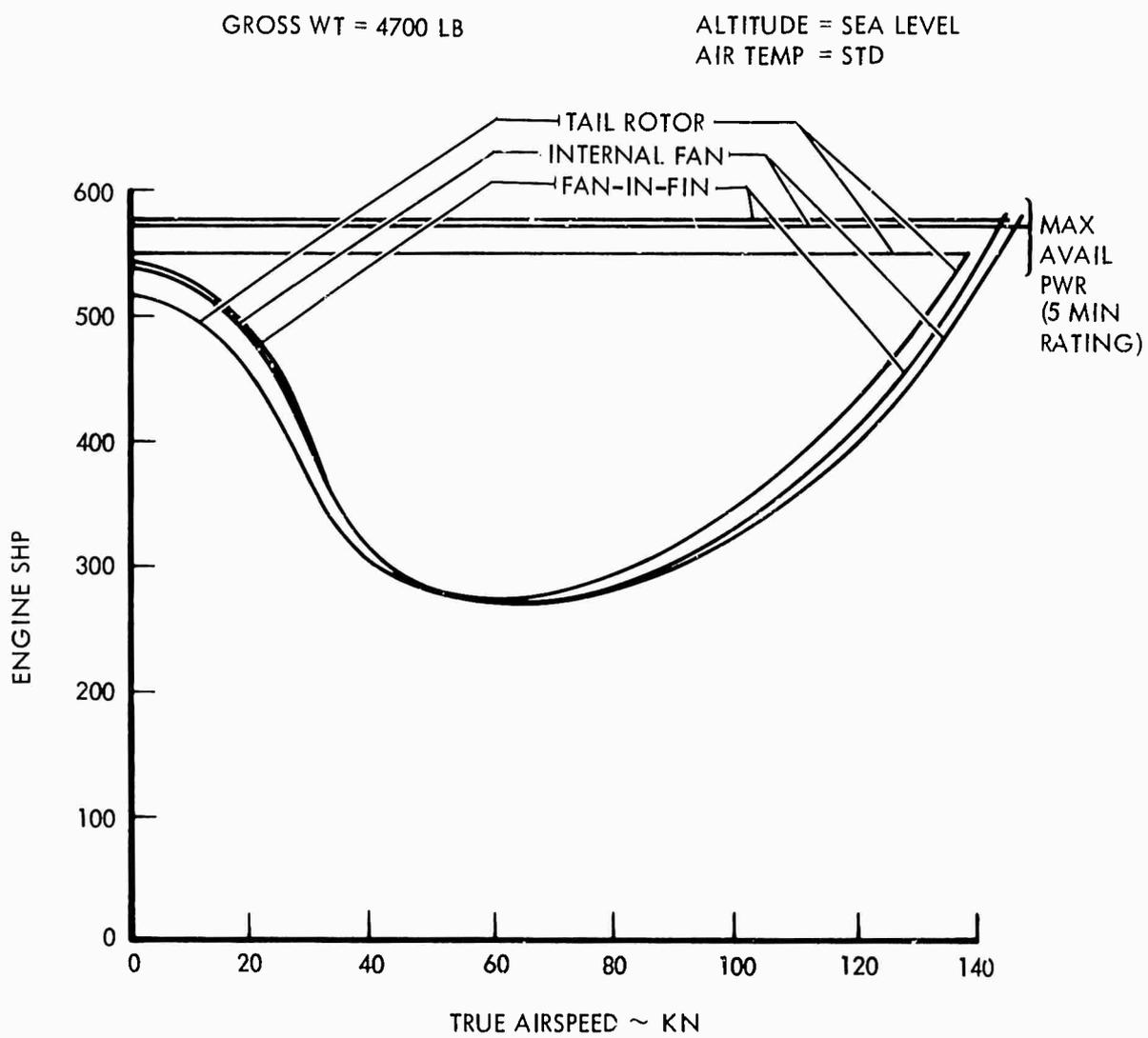


Figure 30. Engine SHP vs. TAS.

MAXIMUM TRUE AIRSPEED

As can be seen from Figure 30 ,

<u>Configuration</u>	<u>Maximum True Airspeed, Knots</u>
Tail Rotor	138
Internal Fan	146
Fan-in-Fin	144

FUEL FLOW AND SPECIFIC RANGE

Figure 31 shows fuel flow for the Model 286. With this information as a basis, and noting Figure 30, Figure 32 was constructed to present fuel flow and specific range for each of the three configurations selected for this study.

PAYLOAD-RANGE

A payload versus range estimate is presented based on a mission consisting of:

1. Two minutes warm-up and takeoff (WUTO) at maximum continuous power; fuel flow = 330 pounds/hour; WUTO fuel = 11 pounds
2. Cruise at 120 knots
3. Reserve fuel = 10% of total fuel

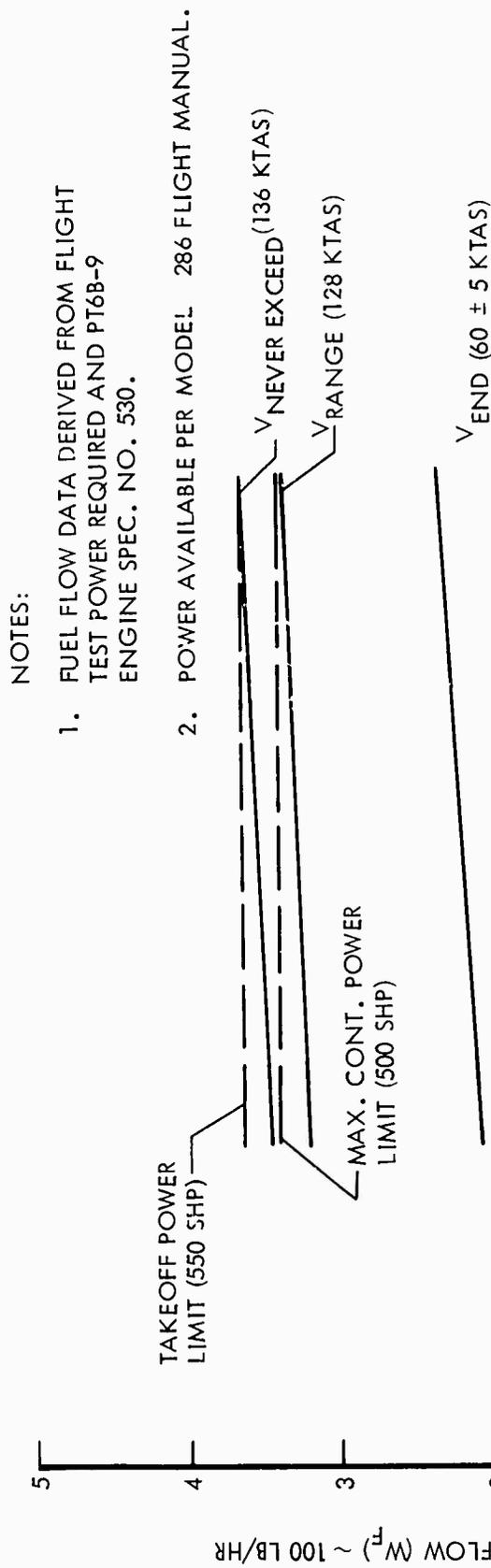
The helicopter weight data used were:

	<u>Tail Rotor</u>	<u>Internal Fan</u>	<u>Fan-in-Fin</u>
1. Weight Empty, (lb)	2998	3026	3023
2. Pilot	170	170	170
3. Trapped Fuel & Oil	19	19	19
4. Engine Oil	<u>18</u>	<u>18</u>	<u>18</u>
5. Operating Weight Empty	3205	3233	3230
6. Gross Weight	4700	4700	4700
7. Useable Fuel + Payload (6) - (5)	1495	1467	1470

Calculations are shown in Table VI, and results are plotted in Figure 33 .
Figure 34 presents the payload differences between the curves of Figure 33 .

MODEL 286 HELICOPTER

SEA LEVEL - STD DAY RPM = 100% FORWARD FLIGHT



GROSS WEIGHT ~ 1000 LB

Figure 31. Fuel Flow vs. Gross Weight.

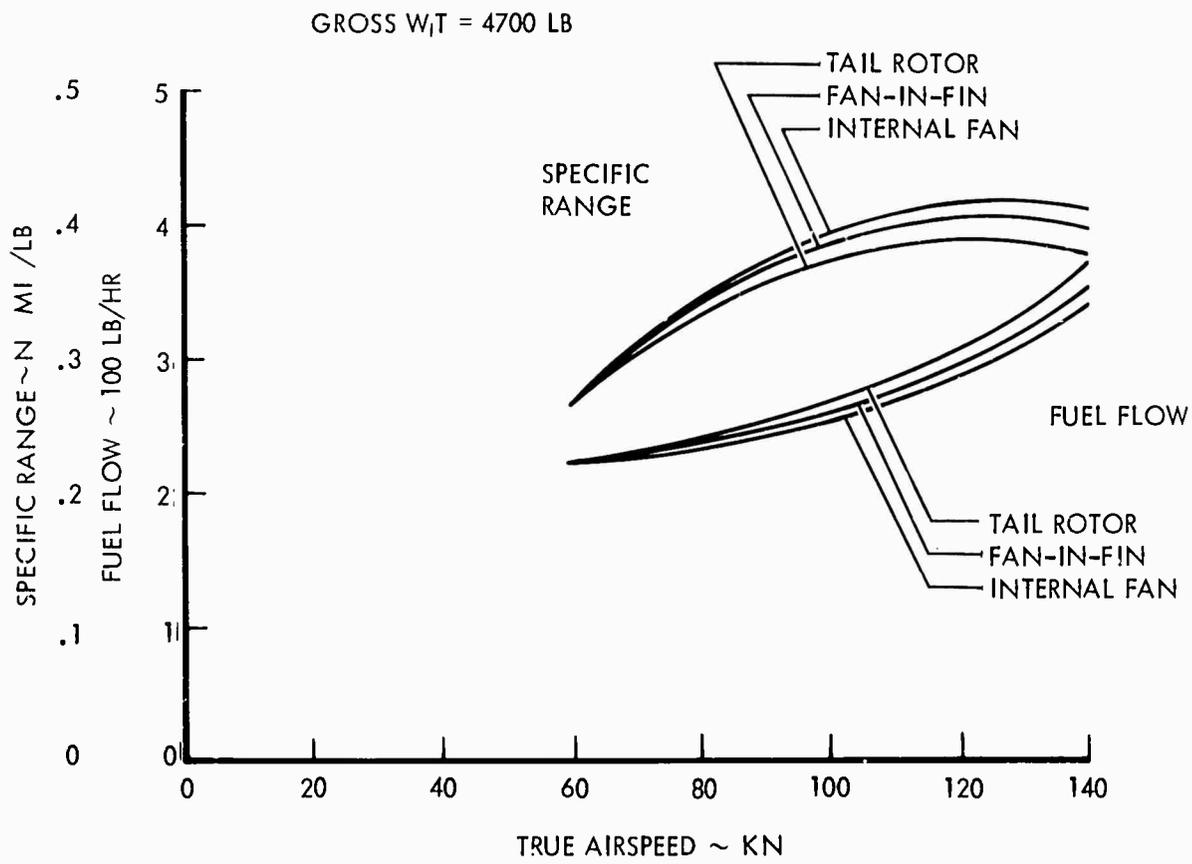


Figure 32. Specific Range and Fuel Flow vs. TAS.

HOVERING GROSS WEIGHT VS. ALTITUDE

Hovering takeoff power is presented in Figure 35 (a reproduction of Figure 32 of Lockheed Report LR 19906*). Using these data and Figure 21, the following tabulation shows the data calculated for Figure 36. Since all configurations were assumed to have an installed SHP increment equal to the extra hovering SHP required for the yawing device, these two figures represent the hovering ceiling data for all three configurations.

Altitude (ft)	$\sigma =$ ρ/ρ_0	SHP (1)	SHP/ σ	W/ σ IGE (2)	W IGE (1b)	W/ σ OGE (2)	W OGE (1b)
S.L.	1.000	550	550	5880	5880	4980	4980
1000	.971	550	556	6040	5850	5100	4950
2000	.943	537	569	6070	5720	5140	4850
4000	.888	514	579	6160	5460	5220	4630
6000	.836	491	587	6220	5200	5275	4410
8000	.786	463	589	6250	4920		
10000	.739	434	588	6240	4610		

(1) Figure 35, Standard Day

(2) Figure 21

Lockheed Model 286 Static Directional Stability

The existing fuselage without the vertical stabilizer was analyzed per the empirical method of the "USAF Stability and Control DATCOM" (page 5.2.3.1-1). The result of the analysis shows that the fuselage has an unstable contribution of $-505 \text{ ft}^3/\text{rad}$ to $\partial(N/q)/\partial\psi$. The existing vertical stabilizer has an area of 11.7 sq ft and a stable contribution of $625 \text{ ft}^3/\text{rad}$ to $\partial(N/q)/\partial\psi$. The existing tail rotor was analyzed using the charts of NASA-TN 2309. At 140 knots, the tail rotor has a stable contribution of $227 \text{ ft}^3/\text{rad}$ to $\partial(N/q)/\partial\psi$.

Thus, when the stabilizing effect of the tail rotor is removed, as in the internal fan and the fan-in-fin configurations, an additional fin area of 4.2 sq ft is provided in the aircraft configurations using either internal fan or the fan-in-fin.

*

W. P. Groth, F. P. Lentine, and R. E. Sadowski, MODEL 286 FAA CERTIFICATION REPORT, Lockheed Report LR 19906, July 1966.

TABLE VI. PAYLOAD VERSUS RANGE CALCULATIONS

		Tail Rotor		Internal Fan		Fan-in-Fin		
1.	Gr wt	lb	4700	4700	4700	4700	4700	4700
2.	Oper. W.E.	lb	3205	3205	3233	3233	3230	3230
3.	Payload	lb	0	993 (a)	0	993	0	993
4.	Total Fuel = (1)-(2)-(3)	lb	1495	502	1467	474	1470	477
5.	WUTO	lb	11	11	11	11	11	11
6.	Res. = .10x(4)	lb	150	50	147	47	147	48
7.	Cruise Fuel = (4)-(5)-(6)	lb	1334	441	1309	416	1312	418
8.	Start Cruise - (1)-(5)	lb	4689	4689	4689	4689	4689	4689
9.	End Cruise = (2)+(3)+(6)	lb	3355	4248	3380	4273	3377	4271
10.	Avg. Gr Wt = [(8)+(9)] /2	lb	4022	4468	4035	4481	4033	4480
11.	Fuel Flow @ 4700 lb							
	Gr Wt (b)	lb/hr	310	310	288	288	296	296
12.	Fuel Flow @ (10) (c)	lb/hr	296	305	277	283	283	292
13.	Hours = (7)/(12)		4.50	1.44	4.72	1.47	4.64	1.43
14.	Range = 120x(13)	n mi	540	173	568	176	557	172
(a) 4 passengers (680 lb) + Baggage (313 lb) (b) Figure 31 at 120 knots (c) (11)x(fuel flow @ 128 kn @ (10)/fuel flow @ 128 kn @ 4700 lb) See Figure 30								

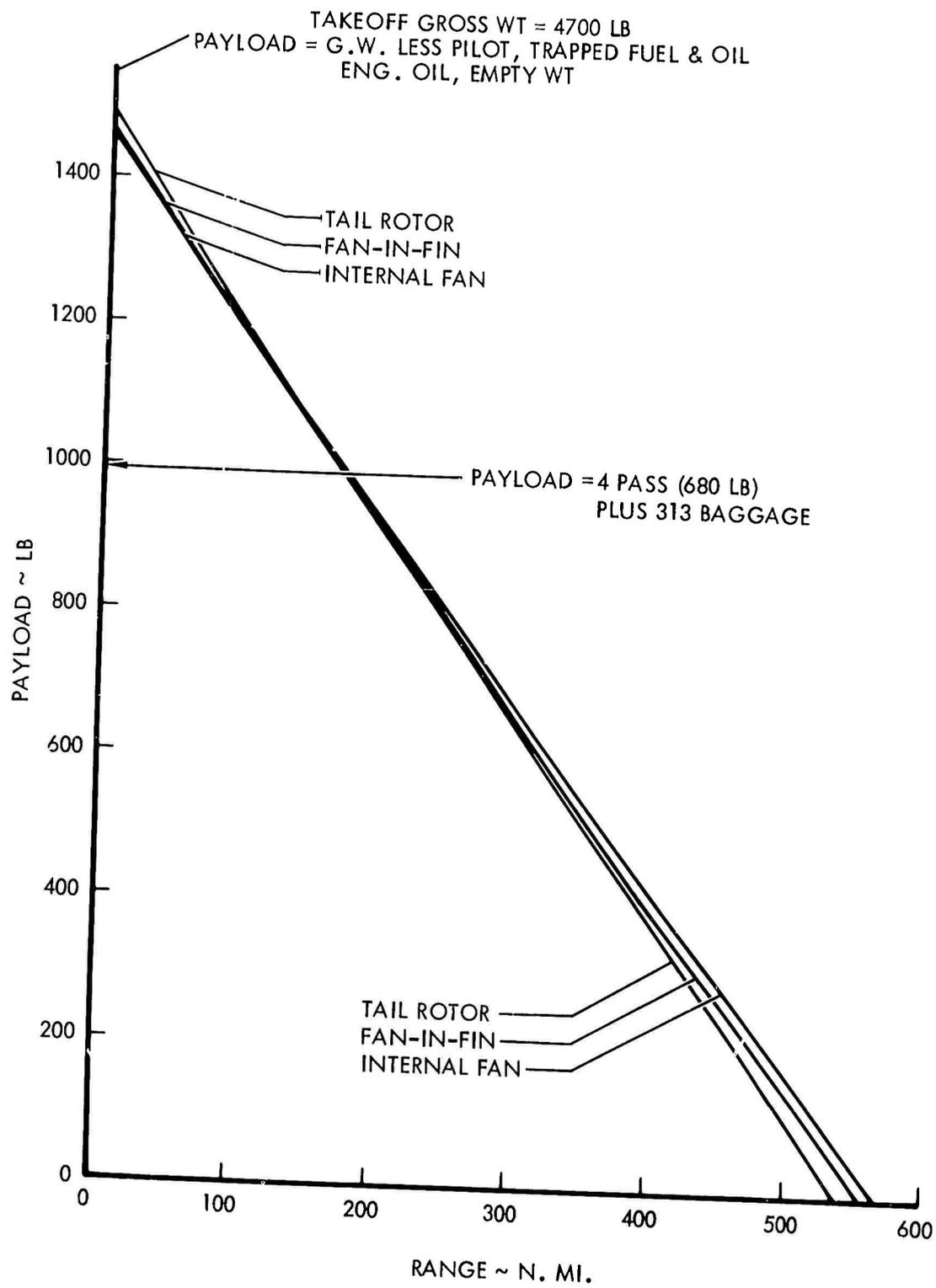


Figure 33. Payload vs. Range.

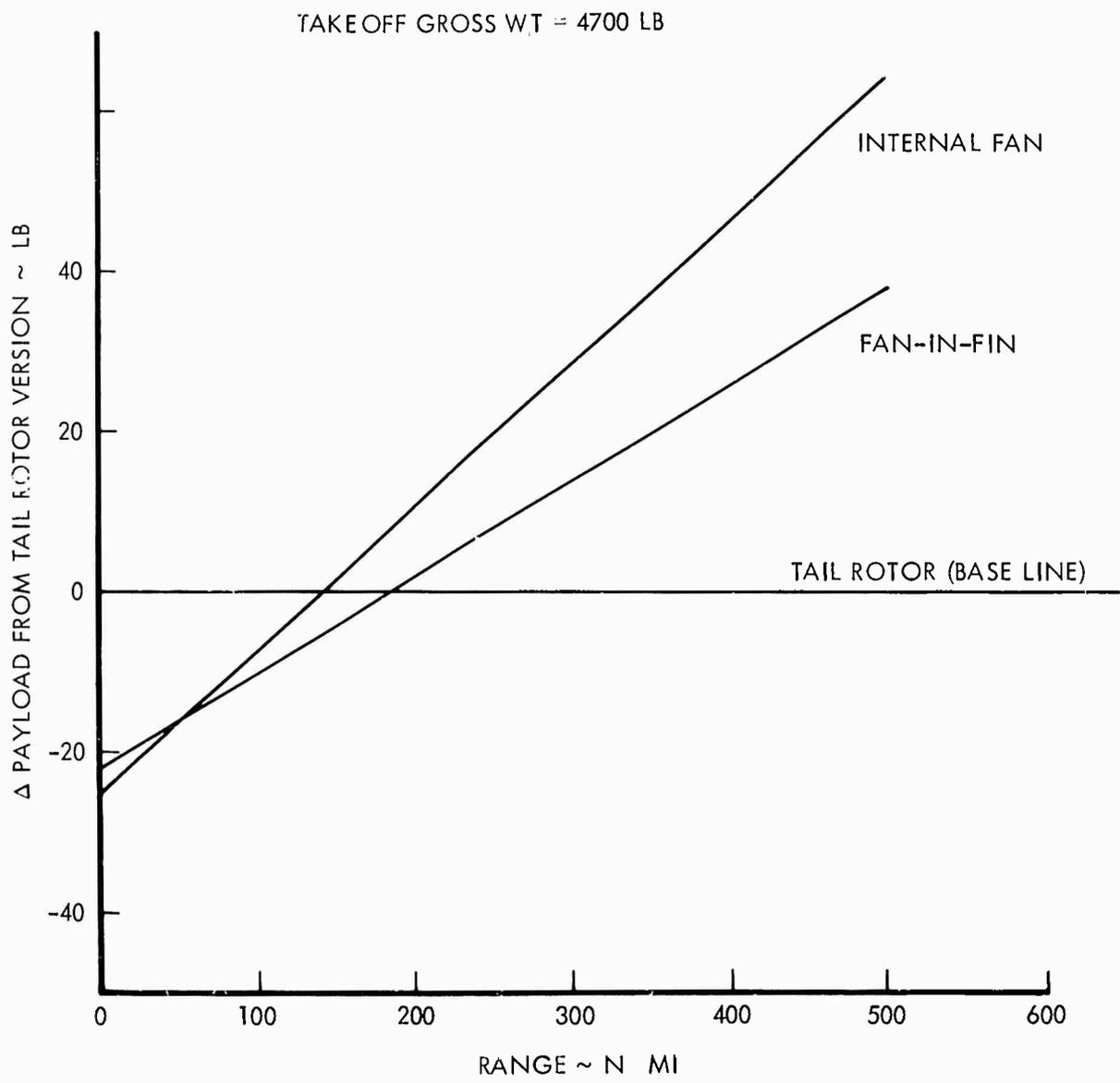


Figure 34. ΔPayload vs. Range

MODEL 286
 INSTALLED TAKEOFF POWER
 CP & W PT6B-9 ENGINE
 JP-4 FUEL

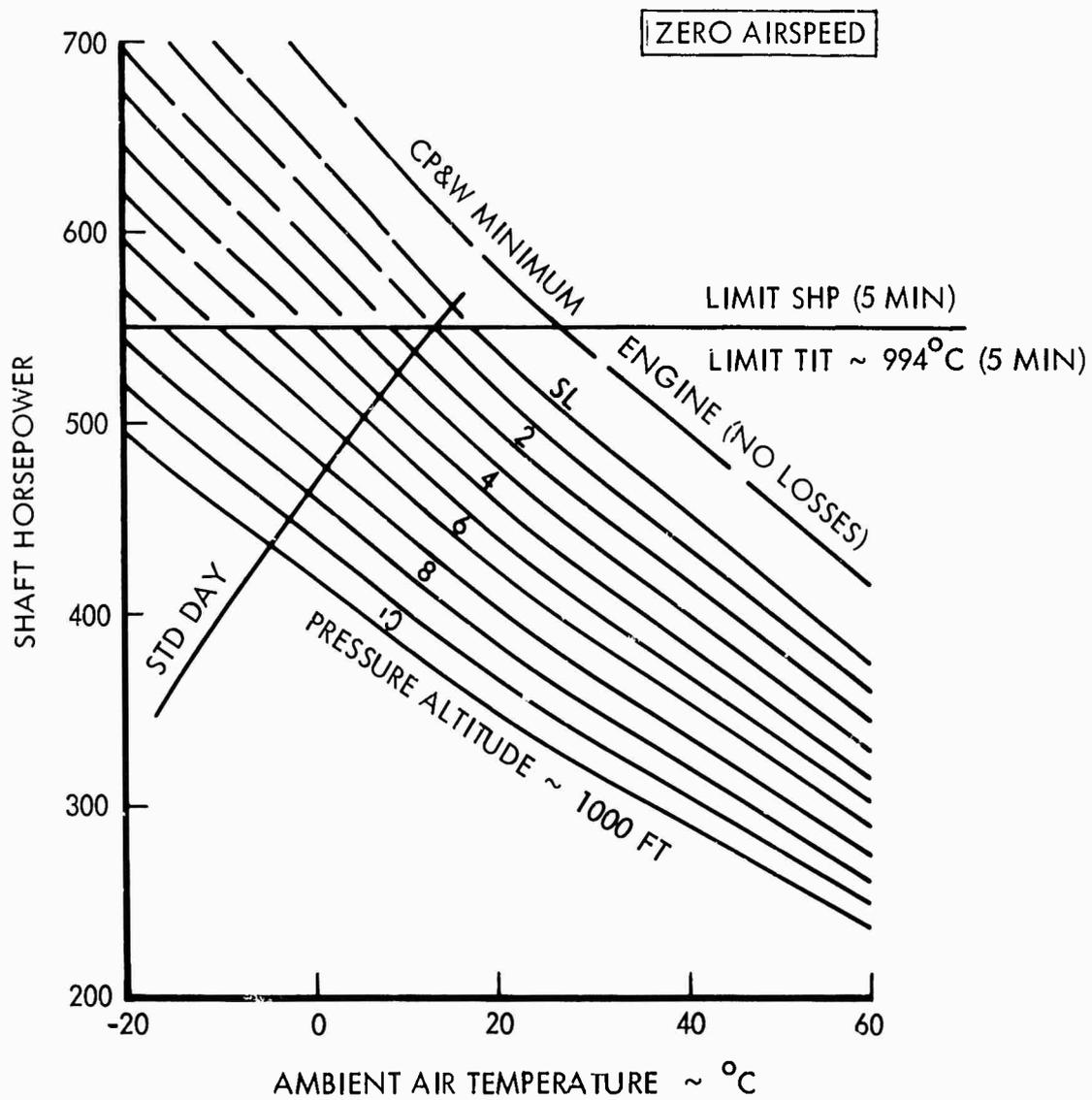


Figure 35. Engine SHP vs. Temperature and Altitude.

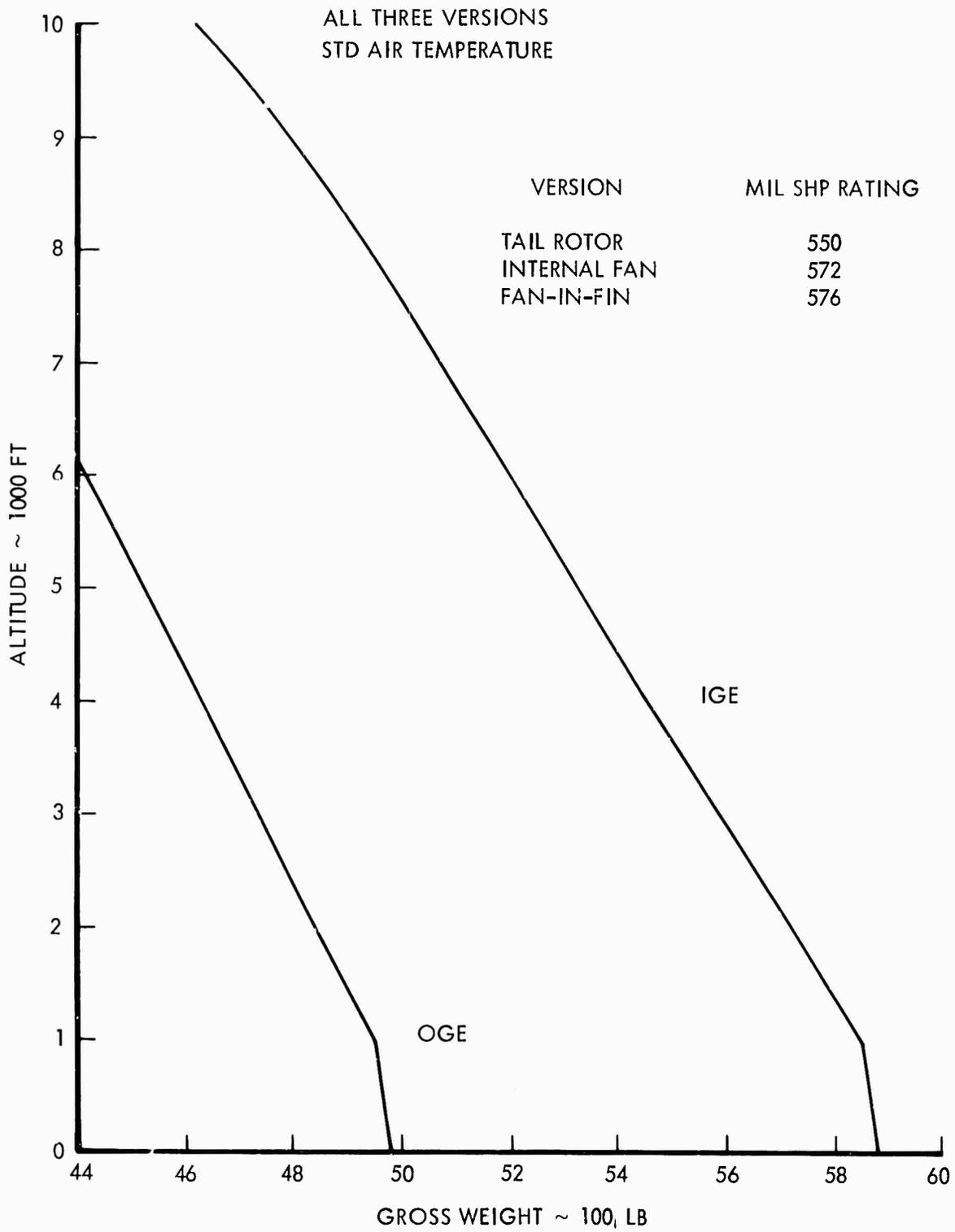


Figure 36. Hover Ceiling vs. Gross Weight.

The foregoing discussion is mainly applicable to large angles of yaw in nearly level flight attitudes. As in most tail-rotor helicopters, marginal directional stability exists in the Model 286 at small angles of yaw and high nose-up attitudes (autorotation descents). This deficiency is remedied in the proposed configurations by distributing the fin area between two fins located in regions of high-energy, relatively undisturbed flow.

7. OPTIMUM-DESIGN NEW VEHICLE

The preliminary designs presented in Section 4 were of necessity compromised in order to qualify as retrofit modifications of an existing Model 286 helicopter. Numerous design improvements could be made if the selected concepts were applied to a totally new design. Two stages of improvement can be considered. The first would eliminate those features that penalized the design because a retrofit was contemplated. The second stage of improvement would result from application of the latest state of the art rotary-wing technology along with the refinement in design over the Model 286 that was designed, not as a fully developed operational production helicopter, but as a minimum-cost research aircraft and demonstrator.

Considering the internal fan configuration, the first-phase improvement would include:

1. Elimination of the belt drive for the fan by use of a direct shaft drive from a power takeoff at the lower end of the main rotor transmission.
2. Redesign of the aft fuselage cross section to a more optimum shape to resist internal pressure, by increasing the space available between the lowest rotor blade position and the ground.
3. Increase of the nose length in order to improve the weight and balance, and optimize the length of the aft fuselage.
4. Selection of an optimum fan design taking full advantage of the generous length of diffuser available.
5. Incorporation of forced circulation slots with optimum load sharing between forced circulation and nozzle thrust.
6. Provision of a fan and drive system capable of accepting full engine power, permitting cruise in nearly full autorotation of the main rotor and full engine power on the auxiliary propulsion system.

The second-phase improvement would include:

1. Optimum disc loading considerably higher than the present 4.9 pounds per square foot.
2. Reduced power loading consistent with the increased disc loading and advanced turbine engine technology.
3. Optimum structural design for minimum weight, including use of new material technology, and advanced fabrication methods.
4. Improved aerodynamic design for minimum drag in forward flight.

The improved forward-flight performance resulting from several of the improvements in both improvement phases would accentuate the advantage of the internal fan concept, since its margin of advantage over the other concepts increases with increased cruise speed. The conceptual sketch shown in Figure 37 illustrates these refinements and the optimum application of the selected anti-torque system.

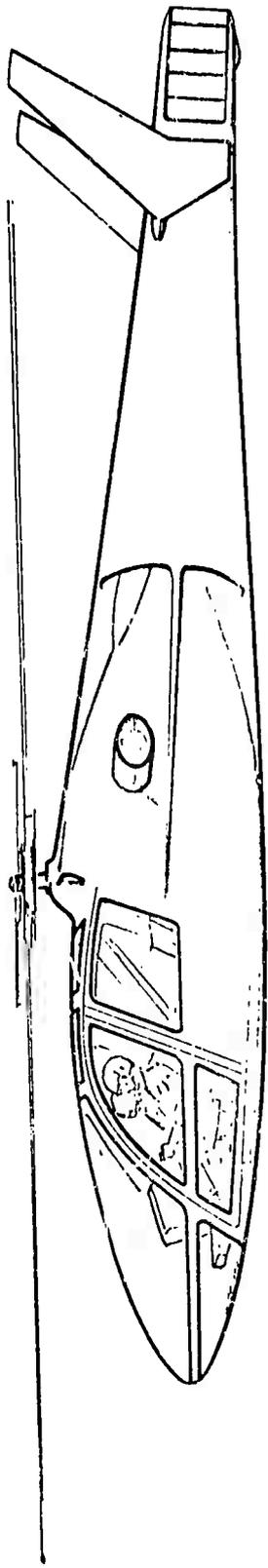


Figure 37. Advanced Technology Anti-Torque Concept.

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APPENDIX
LITERATURE SEARCH RESULTS

The anti-torque devices found in the literature search were grouped into the categories listed previously in the "Survey of Potential Concepts", Section 2. Brief descriptions of many representative concepts are included in this appendix, grouped as follows:

1. Conventional tail rotors
2. Ducted fans
3. Nozzles
4. Immersed aerodynamic surfaces
5. Horizontal-axis rotary-wing airfoils
6. Future concepts

In general, each item discussed in this appendix summarizes an item of literature and references that item. A list of the references cited herein is given in the Literature Cited section.

1. CONVENTIONAL TAIL ROTORS

"Tail Rotor Design", References 1-1 and 1-2

From the power-requirement point of view, the low disc loading tail rotor is by far the most efficient approach to torque compensation and directional control for a single-rotor helicopter. However, experience on a wide variety of helicopters has shown that it is far from a simple task to develop a tail rotor installation that has completely acceptable control, stability and structural characteristics.

A tail rotor is often thought of, incorrectly, as a propeller or a small main rotor. Unlike a propeller, the tail rotor must produce thrust with the free air coming from all directions. Unlike a main rotor, a tail rotor is not trimmed for wind or flight velocities. It operates in an extremely adverse environment and must produce both positive and negative thrust.

These papers consider the aspects of good tail rotor design in two parts. Part I, "Aerodynamics," defines principal tail rotor design criteria. The various related aerodynamic items and parameters are discussed. Part II, "Structural Dynamics," considers the dynamics of stiff in-plane tail rotor designs.

The tail rotor should be designed for one of the following conditions:

1. The aircraft's critical hovering attitude and temperature
2. The engine critical attitude

The first step in the design is to establish the maximum required thrust and the conditions under which it must be produced. Experience shows that the maximum conditions usually occur during hover and low-speed yaw.

Stall due to precession is most likely to occur whenever there is a combination of high tail rotor thrust and high yaw rate. Precessional stall can be delayed by increasing the airfoil C_L max, the blade Lock number or the tail rotor tip speed.

Based on review of flight data on Bell helicopters it has been found that oscillatory structural loading of the tail rotor is not significant at frequencies greater than 150 Hz. It is believed that the 150 Hz frequency is an acceptable frequency upper limit for tail rotors of conventional design and construction for medium-sized helicopters.

Tail rotor loads are significantly affected by the shaft mounting stiffness. Pitch-flap coupling has been identified as the cause of tail wagging. Negative δ_3 appears to be the best solution for this condition, since it increases the damping of the tail boom modes.

"Control Means for Rotating Wing Aircraft", Reference 1-3

This invention develops anti-torque from two anti-torque rotors mounted at the end of the body at an inclination of about 45° from the vertical so that their axis of rotation forms an upright V. By the application of equal or differential rotor pitch, this arrangement provides vertical lift in addition to pitching and yawing moments.

This concept compounds the existing tail rotor complexity without relieving any of its inherent problems.

A sketch from the patent is shown in Figure 38.

"Convertiplane", Reference 1-4

An invention is shown which uses an anti-torque rotor which is permitted to rotate 90° about a vertical axis passing through the tail rotor gearbox until it assumes the position of a pusher propeller; although this invention appears workable, it does not change the manner of operation of the present anti-torque rotor.

The invention is illustrated in Figure 39.

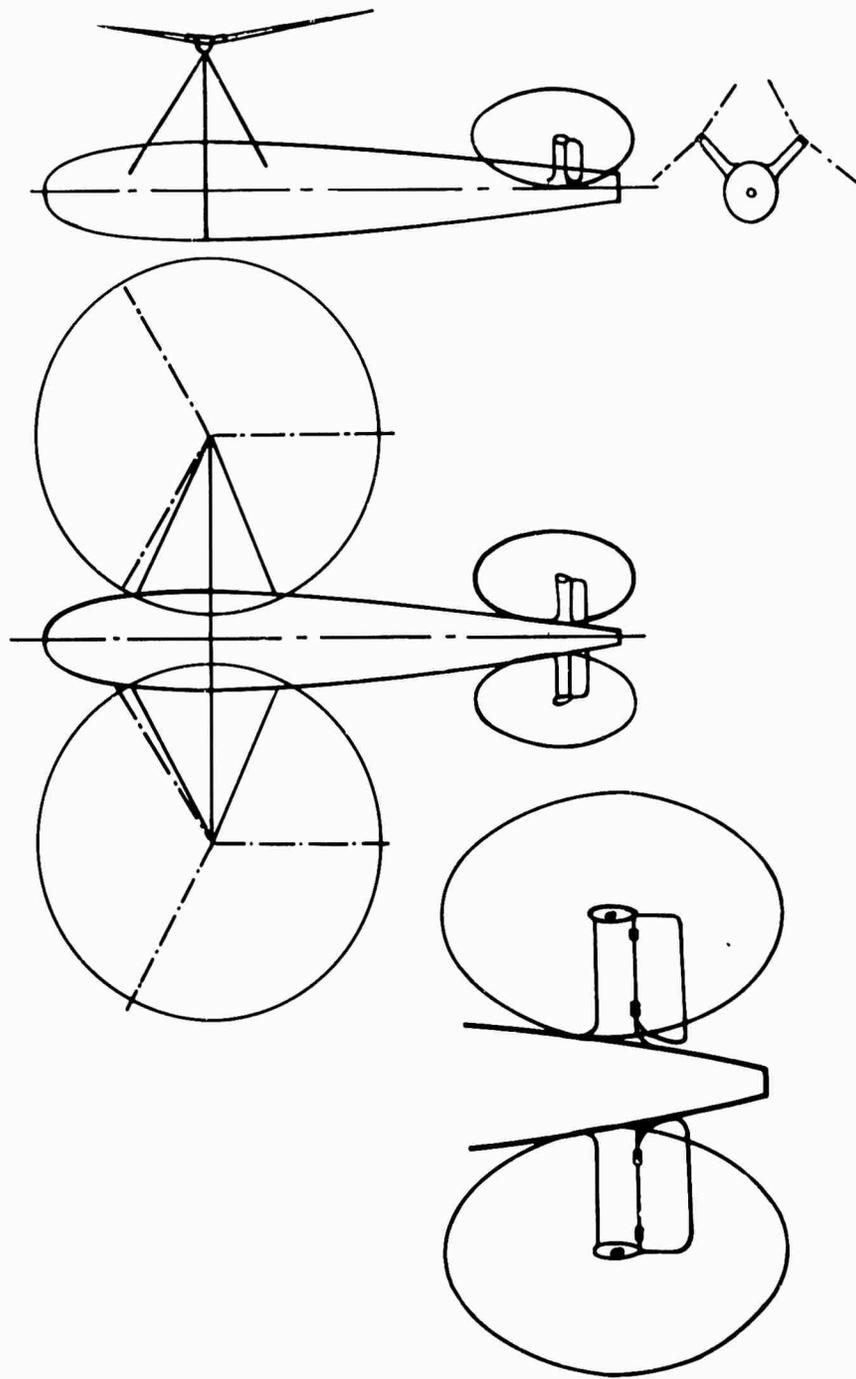


Figure 38. Control Means for Rotating Wing Aircraft,
Pat. No. 2,225,002.

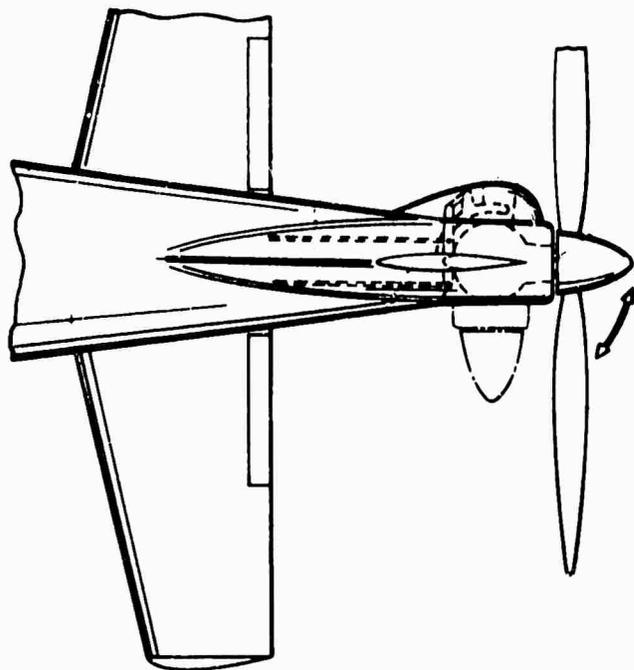
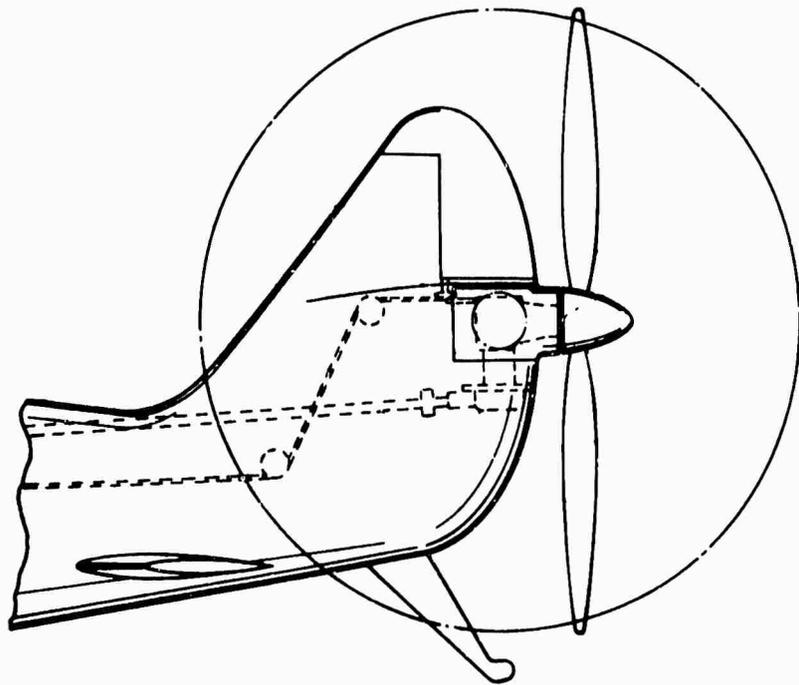


Figure 39. Convertiplane, Pat. No. 3,155,341.

2. DUCTED FANS

"Fenestron", Reference 2-1

The shrouded tail rotor developed by the Societe Nationale Industrielle Aerospatiale for the SA.341 "Gazelle" eliminates most disadvantages of the conventional tail rotor of shaft-driven helicopters. Protected by the tail fin, in which it is enclosed, there is no risk of the tail rotor touching the ground during approach landing; impact with any object becomes practically impossible.

Total aircraft power required in hovering is 3-4% higher than for a conventional tail rotor, but less power is needed in forward flight. A cambered airfoil tail fin relieves the tail rotor transmission system of anti-torque load in forward flight. This feature enables the aircraft to return to base, should the fan drive become inoperative.

Considering the low values of alternating stresses in the blades and control components, this system is particularly attractive for high-speed rotary-wing aircraft.

Several variations of the Fenestron concept are shown in Figures 40, 41, 42 and 43.

"Gazelle", Reference 2-2

This reference give additional information on the vehicle in which the fan discussed above is employed. The ducted fan tail rotor, colloquially called "Fenestron", is a feature of the "Gazelle". The fan is described as a multibladed rotor, hinged in pitch only, rotating within a shroud in the vertical fin. The advantages of a shrouded tail rotor are:

Technical:

- o Short cantilever blades not as subject to instability as conventional flap hinged tail rotor
- o Blades work at low stress levels
- o Rear transmission system not loaded most of time, except in hover
- o Tail pylon and intermediate gearbox not required

Operational:

- o Safety for ground personnel and from terrain-contact damage
- o Ability to return to base in a forward flight mode in case of tail rotor transmission rupture instead of need for an immediate autorotation landing

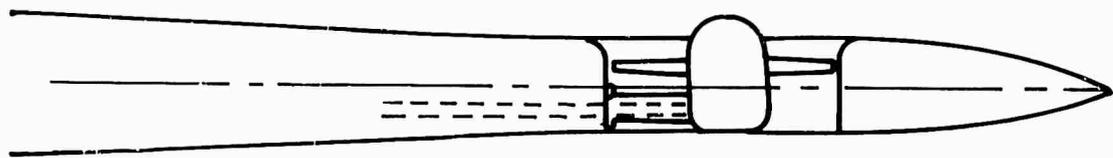
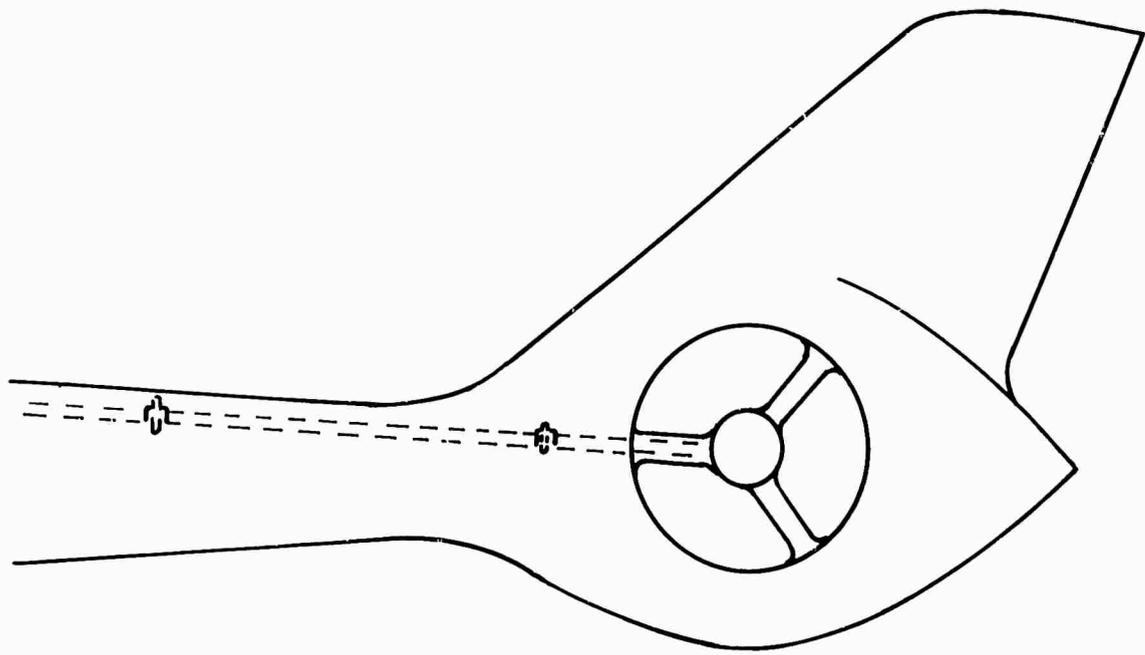


Figure 40. Ducted Fan-in-Fin, Compact Size.

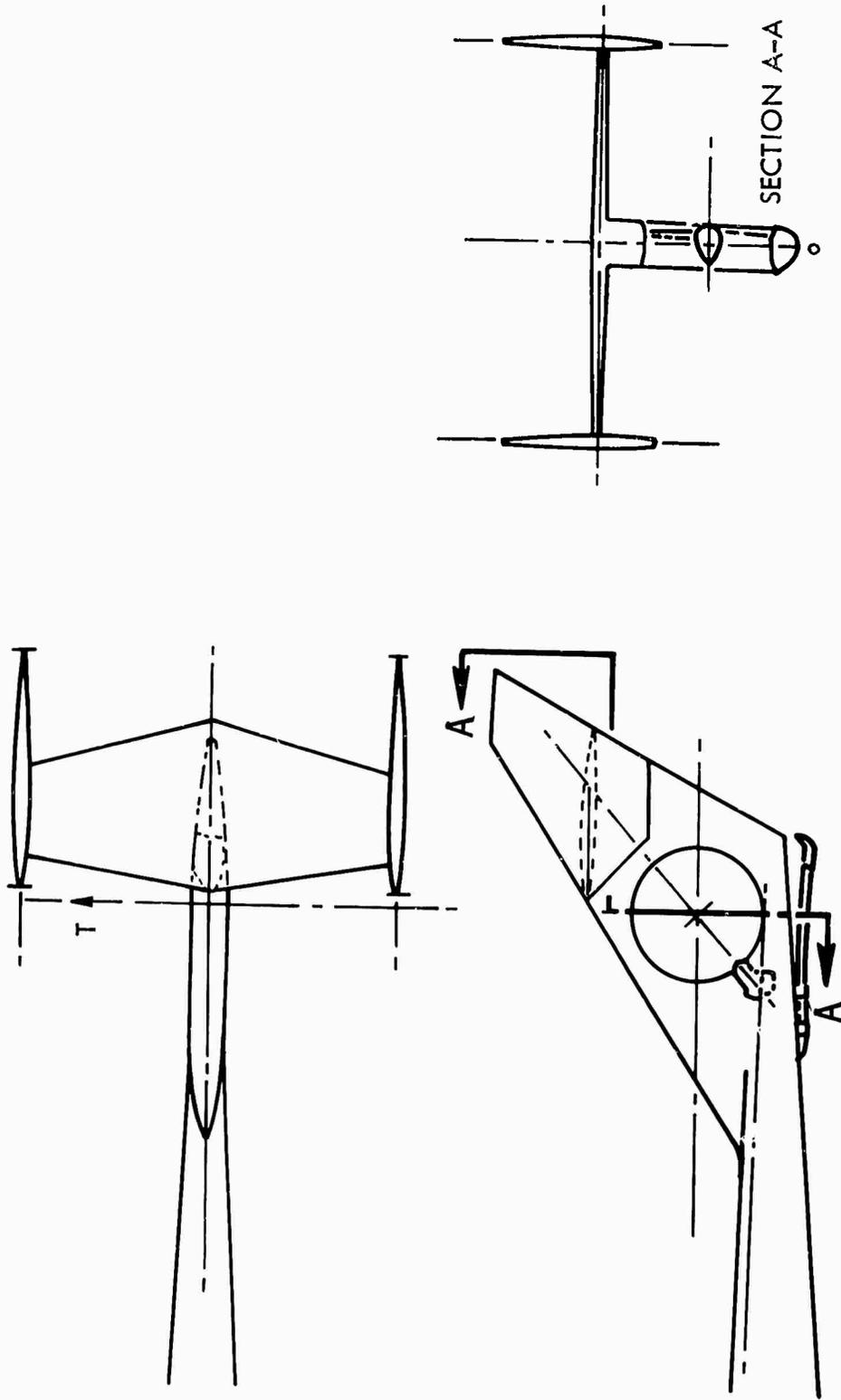
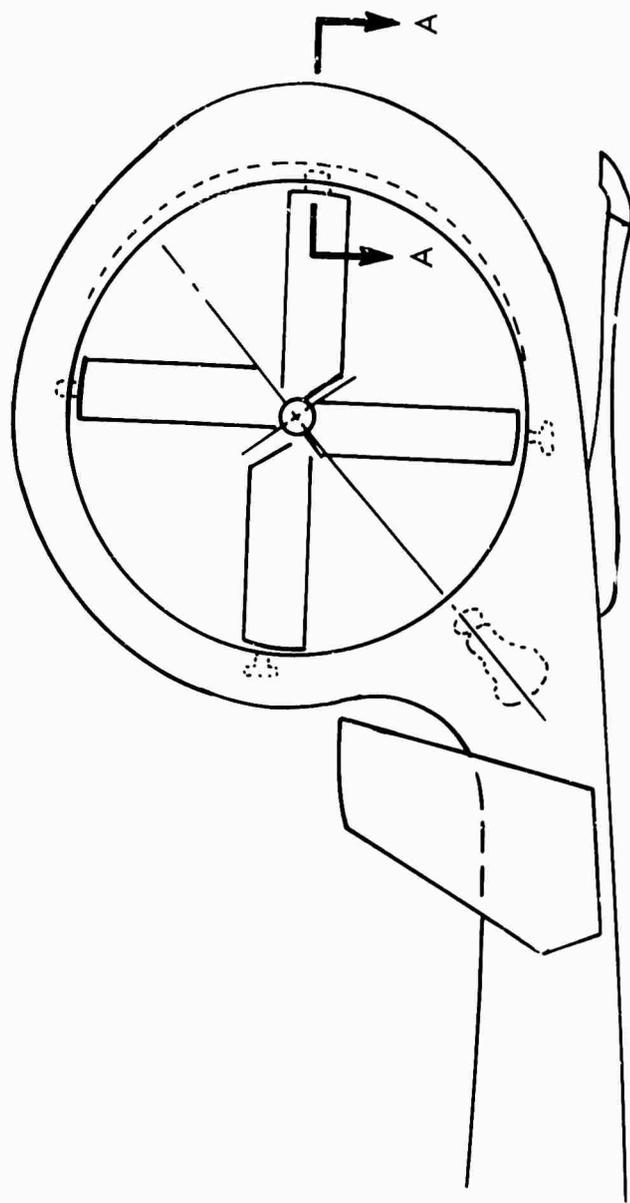


Figure 41. Ducted Fan-in-Fin, Intermediate Disc Loading.



SECTION A-A
 BLADE TIPS RESTRAINED BY
 SHOES RIDING INSIDE
 CIRCUMFERENTIAL SLOT
 ON AIR CUSHION PADS

Figure 42. Shrouded Fan, Low Disc Loading.

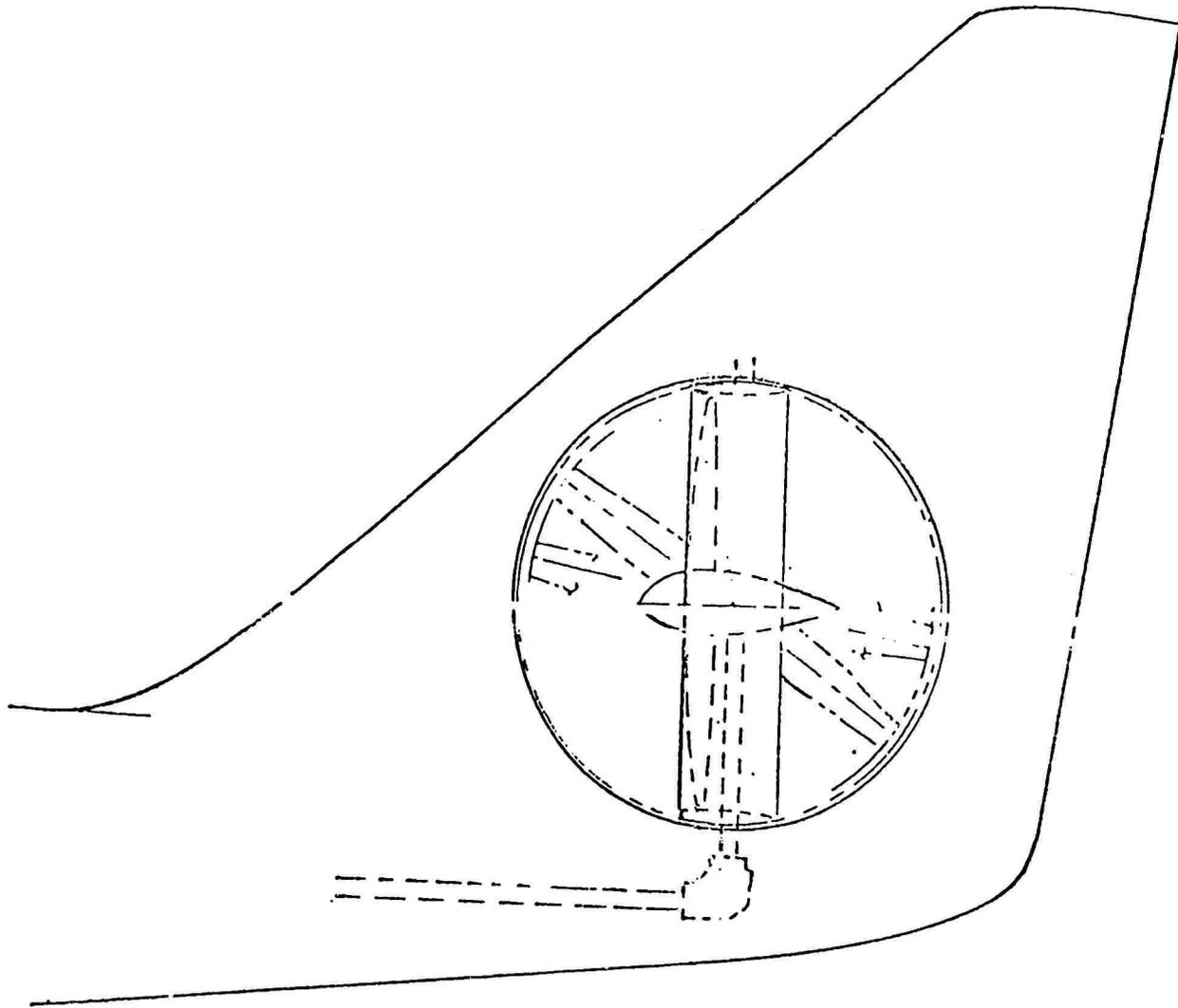


Figure 43. Swiveling Ducted Fan (Tail Mounted).

- o Low vulnerability
- o Low maintenance. The power drawn by the rotor in forward flight cruise (maximum percent of time) is very low, thus extending mean time between overhaul. Low fatigue stresses lead to an infinite service life. No lubrication is required.

"Ducted Propeller Study", Reference 2-5

Various aspects of ducted propeller theory and design are considered. These include the lift of a moderately inclined ducted propeller, possibilities for increasing the static thrust, blade design, and flow field analysis of interference with adjoining wings or bodies.

The inclined duct theory is shown to be in agreement with test data from different sources.

Large ratios of static thrust to horsepower are predicted at low jet velocities for designs which accelerate the inflow in accordance with specified pressure changes inside the duct. For such flows, blade designs are shown by means of solidity pitch distribution, jet velocity and tip speed.

Digital computer studies are recommended to evaluate favorable and unfavorable interference flow arrangements between ducted systems and surrounding surfaces. The fan-in-wing flow field with a jet of finite size is one of many cases which can be handled.

"Comparative Performance Charts for Ducted Propellers", Reference 2-7

In hovering flight, the ducted propeller is shown to have superior figure of merit to that of an open propeller. It is shown that the ideal figure of merit for a ducted propeller is approached as the ratio of the maximum duct diameter to propeller diameter is increased, and if proper attention is given to inlet shape and propeller configuration.

In axial flow, it is shown that the propulsive efficiency is a function of duct diffuser angle and advance ratio. The diffused duct gave approximately 17% better efficiency than the nondiffused duct and surpassed that of the open propeller in the low-speed regime. It is as good as the open propeller up to an advance ratio of approximately 0.4 to 0.6, after which the open propeller appears to have superior efficiency.

It appears that the wake diameter of a two-dimensional ducted propeller increases with increasing duct diffuser angle and decreases in size as the duct chord to propeller diameter ratio decreases. However, due to uncertainties in water tests which were conducted, the results are not conclusive.

"Determination of Design Parameters for Optimum Heavily Loaded Ducted Fans",
Reference 2-3

Like the free propeller in axial flight, a single-rotation ducted fan of high induced efficiency is characterized by an ultimate wake vortex system shed from the blade trailing edge whose apparent motion is that of rigid helical surfaces. In addition, however, concentric with this inner sheet there is a cylindrical surface of helical vortex filaments shed from the duct trailing edge. For a theoretically zero hub diameter, and neglecting compressibility, viscosity, and tip clearance, a mathematical model of the constant-diameter vortex wake is developed and the compatibility relationships to be satisfied are presented. Using the Biot-Savart equation, the vortex strength distribution in the wake is determined by numerical methods and is then rotated to the blade bound vortex strength.

The integrations required to generate the velocity component contributions of a helical vortex filament have been programmed on a digital computer. Initial calculations were made for the limiting case of a single turn of the helix at zero helix pitch angle for comparison with ring vortex analysis results. The comparison was satisfactory, and the calculations were then extended to obtain the velocity contributions of a full helical vortex filament which is the basic element of the vortex system to be considered. Provision was made for an internal determination of the angular interval of numerical integration required for a specified degree of accuracy and for the permissible truncation of the infinite length of the filament.

"Three-Dimensional Theory of Ducted Propellers", Reference 2-6

A three-dimensional theory was developed for the ducted propeller with a finite number of blades in uniform motion through an inviscid, incompressible fluid at zero incidence. Within the approximations of a lightly loaded propeller and thin airfoil theory, the following generalizations were obtained:

- o The effect of shroud camber appears only in the steady shroud load.
- o The steady pressure difference across the shroud is identical to that of a similar ring wing of different camber.
- o At high advance ratio, the resultant shroud loading is equal to the load on the isolated shroud plus the loading on an equivalent asymmetric ring wing.
- o The steady pressure distribution on the shroud corresponds to the total loading on a similar configuration with infinite blade number but the same radial disc loading.
- o The steady part of the flow field of any propeller with finite blade number corresponds to a generalized actuator disc solution with the same radial disc loading.

"Theoretical Investigation of Ducted Propeller Aerodynamics", Reference 2-4

It is shown that the propeller duct serves only one useful purpose: to reduce the propeller diameter. It appears that all other effects are unfavorable.

The ducted fan experiments reviewed cover a wide variety of characteristics. For example, area loadings of these machines extend from 4 to 150 psf. Operational conditions vary from nearly static to operation at high forward speeds.

Some general principles become apparent. Gains in efficiency over the free propeller cannot be obtained by a shrouded propeller or fan. This is true for configurations designed for static operation as well as for forward flight. The shrouded propeller can, however, produce higher static thrust than a free propeller of the same diameter and can do this efficiently if correctly designed for operation in a shroud.

The ducted configuration also offers the opportunity to add stators. These are important for very highly loaded systems; and it appears that in this area of extremely high loadings, a case for the ducted fan can be made. The ducted fan configuration could be a natural solution if the necessity exists to adapt a design to special constructive requirements, such as to store the fan during high-speed flight.

It is evident that the ducted fan system is justified more from constructive requirements than from fluid mechanic gains.

"Convertiplane", Reference 2-8

An invention is described which uses a combination of tilt-wing-mounted propellers, tail-mounted vertical thrust ducted fan and tail-mounted horizontal thrust ducted fan in addition to standard aircraft controls of rudder, aileron, and elevator to control and maneuver the vehicle.

The primary yaw control is obtained from the joint use of the vehicle's rudder and horizontal thrust ducted fan. Figure 44 illustrates the concept.

"Helicopter Steering and Propelling Device", Reference 2-9

A helicopter is described in which the forward thrust capability is supplemented by a pusher propeller located on the aft end of the vertical stabilizer. In addition, a ducted fan installed within the vertical stabilizer functions as the yaw control device for the vehicle. The invention relates in part to the mechanical gearing and shafting of the shrouded tail rotor and propeller. The concept is illustrated in Figure 45.

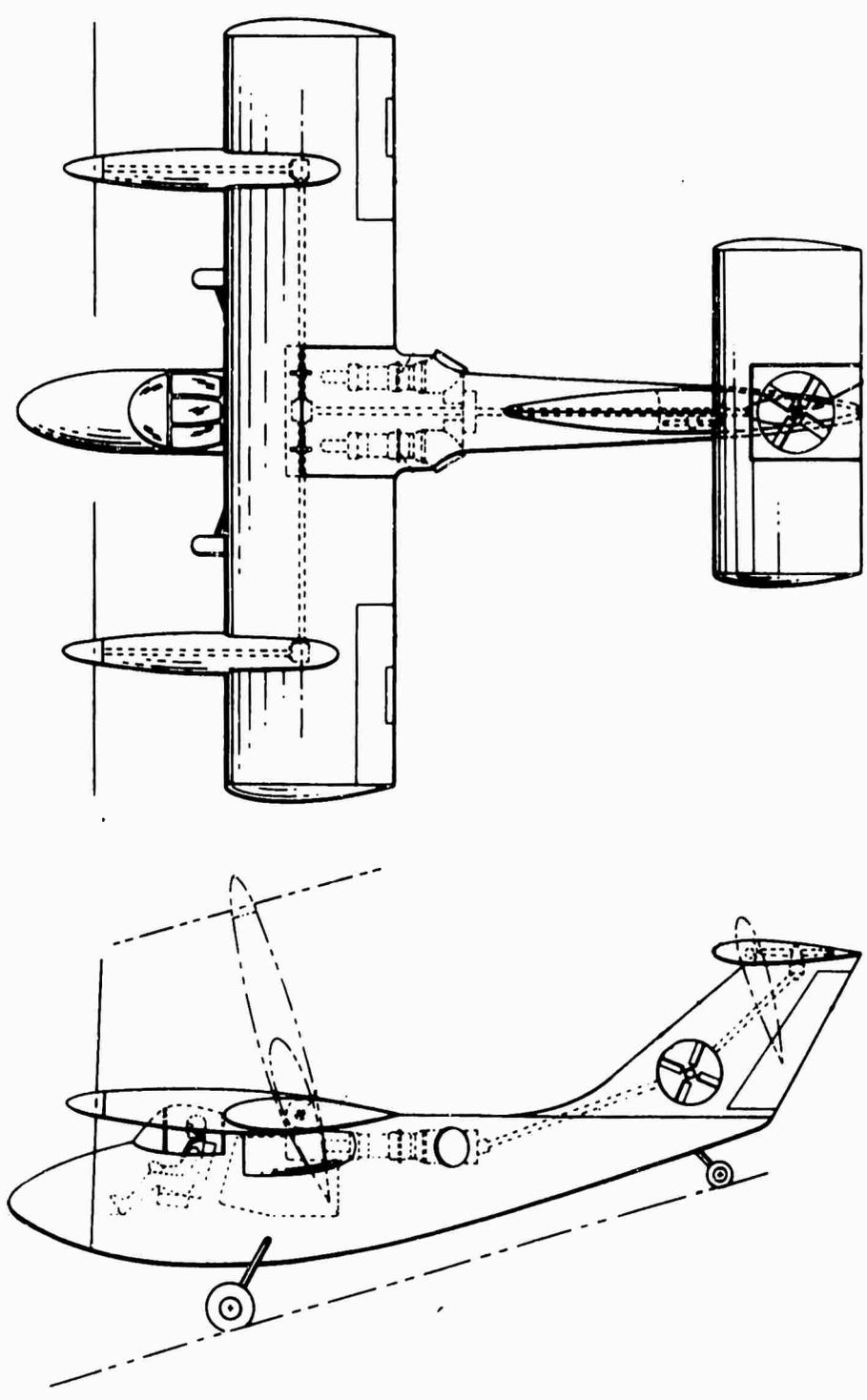


Figure 44. Convertiplane, Pat. No. 2,936,967.

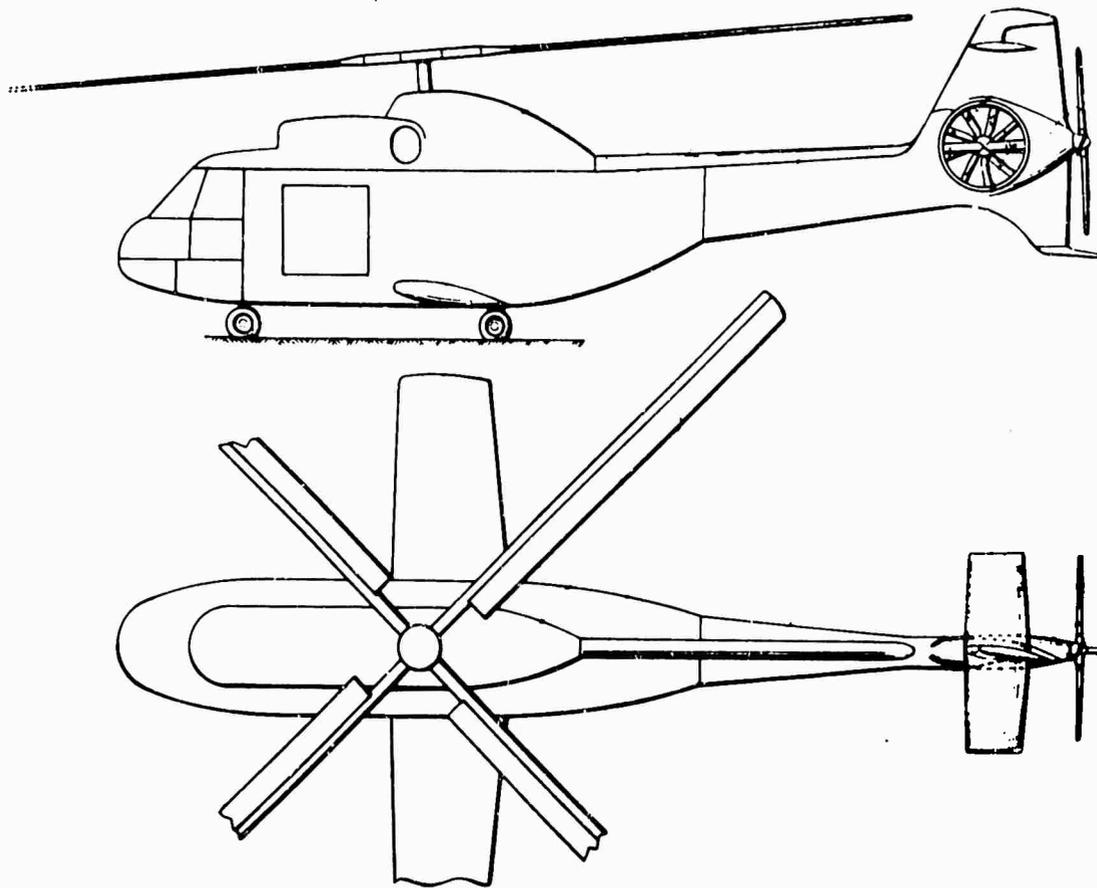


Figure 45. Helicopter Steering and Propelling Device,
Pat. No. 3,506,219.

"Improvements in or Relating to Helicopters", Reference 2-10

A helicopter is described in which a tail rotor, which operates off a drive shaft attached to the main rotor gear train, is internally mounted in the aft fuselage. The rotor drives air across the aft fuselage through controllable louvers located on both sides of the fuselage adjacent to the rotor. This causes a thrust acting about the helicopter c.g. and counter rotating relative to the main rotor torque. A gyro "hunting" type system is employed to throttle main rotor power when the torque is at the limit of the tail rotor capacity. The concept is illustrated in Figure 46.

"Helicopters With Counterrotating Propeller", Reference 2-11

The configuration covered by this patent develops lift with a high-speed counterrotating ducted propeller, and lift plus directional control with a low-speed rotor mounted coaxially and above the ducted propeller. The ducted propeller can be fixed pitch. The low-speed rotor is controlled in pitch collectively and cyclically as in conventional helicopters. Figure 47 illustrates the concept.

"Helicopter", Reference 2-12

An invention is shown which includes a ducted fan mounted within the aft fuselage in a transverse position. The duct openings are provided with louvers which can be closed for forward flight to produce a smooth exterior surface.

The anti-torque effect required in normal forward flight is provided by an aerodynamically contoured vertical stabilizer to produce anti-torque aerodynamic forces.

The anti-torque features of this invention as described above are practicable; however, the location of the anti-torque fan could be improved to reduce power required to drive this system. The concept is illustrated in Figure 46 (same as discussed above relative to Reference 2-10).

"Long-Range Convertible Helicopter", Reference 2-13

This patent covers a vehicle configuration that can be converted on the ground into either a helicopter or a fixed-wing aircraft. The main rotor, in the helicopter mode, doubles as a fixed wing in the airplane mode. This patent covers the yaw control, which comprises a shaft-driven ducted fan inside the vertical tail. Movable vanes cover or expose the tail rotor in accordance with the requirements of its operational mode as helicopter or airplane. The tail conversion procedure is illustrated in Figure 48.

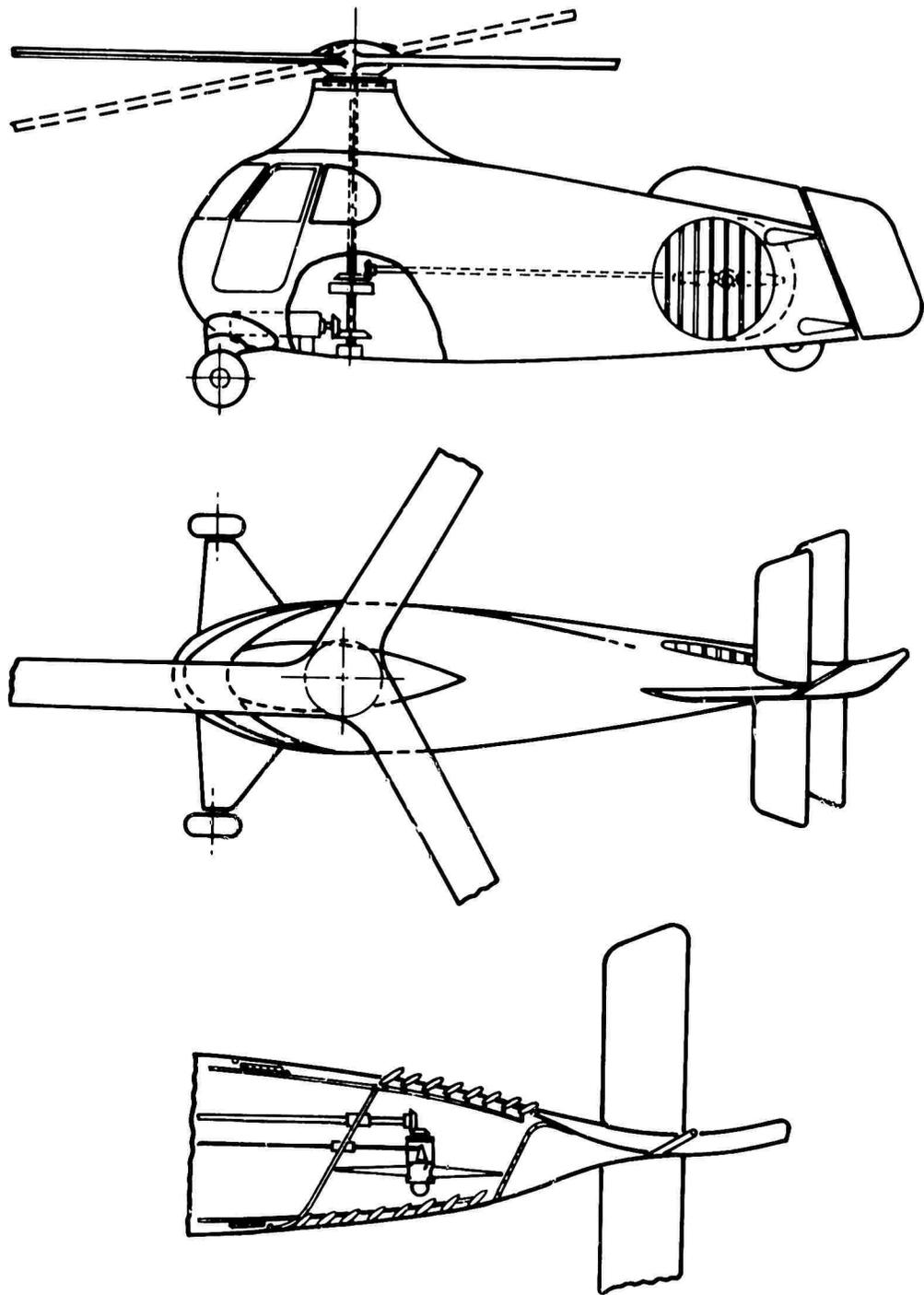


Figure 46. Helicopter, British Pat. No. 606,420 and U.S. Patent No. 2,369,652.

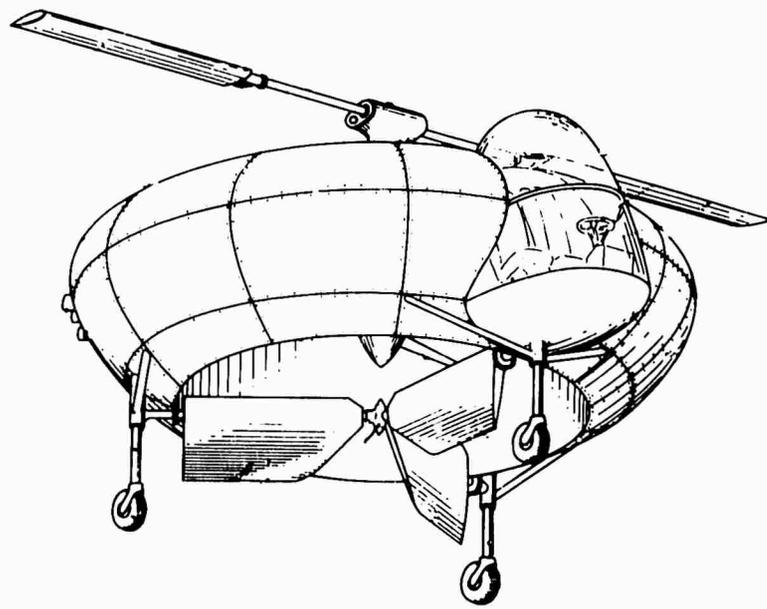
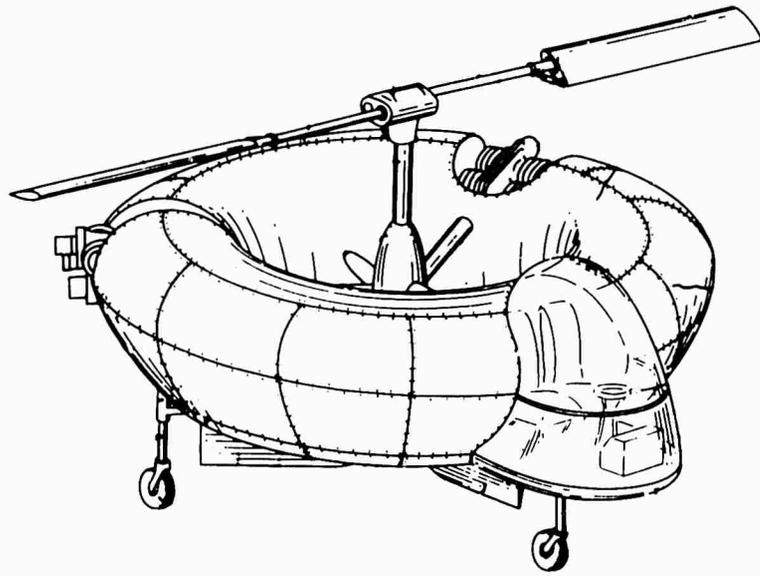


Figure 47. Helicopter With Counterrotating Propeller,
Pat. No. 2,996,269.

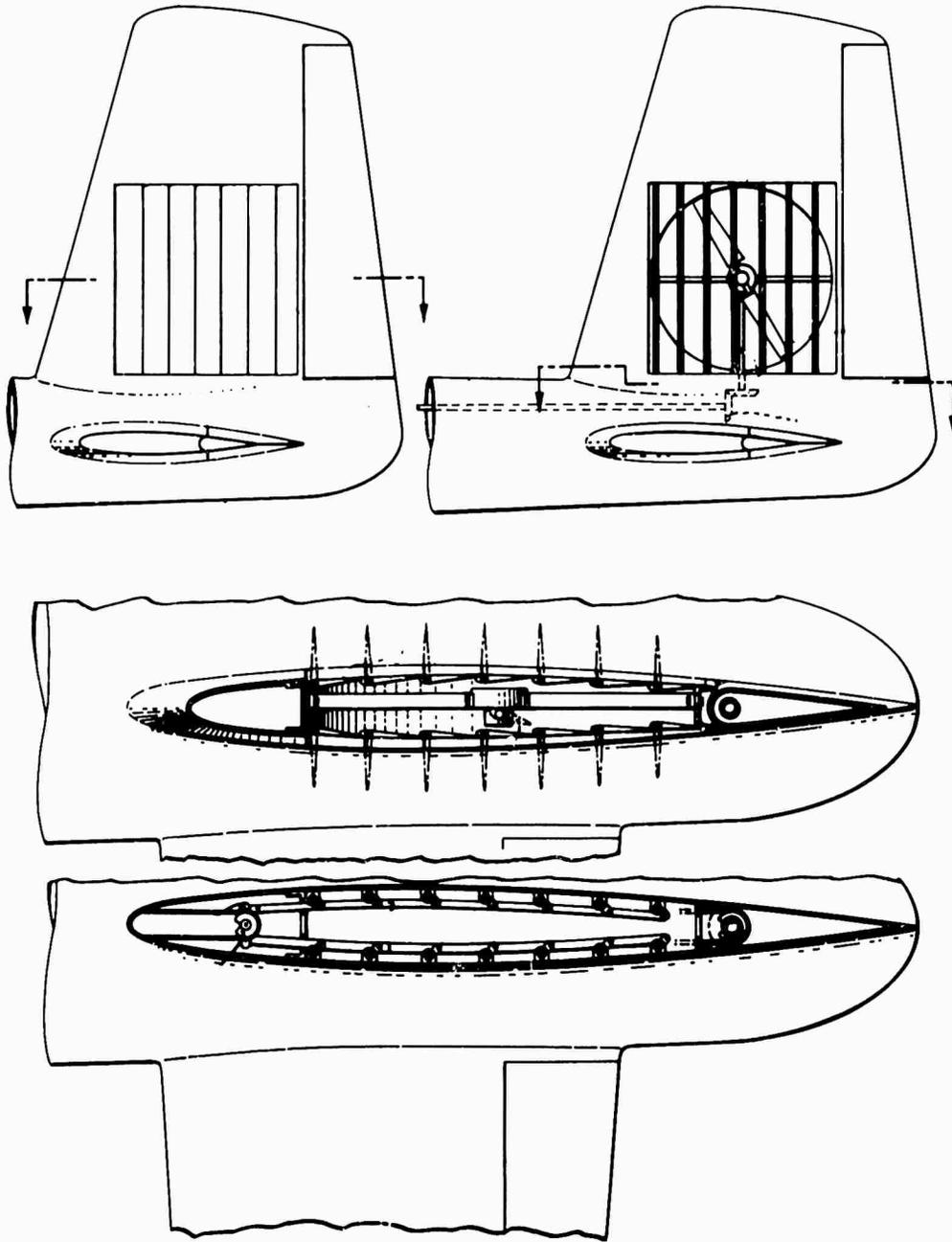


Figure 48. Longe-Range Convertible Helicopter,
Pat. No. 3,116,036.

3. NOZZLES

"Ejectors, or the Ejector Wing, Applied to V/STOL Aircraft", Reference 3-1

Ejectors currently under study and development by the Bertin Company are described in the reference and some experimental results are shown. Thrust augmentation ratios as high as 2.3, with diffusion of the mixed air, have been achieved using multistage, concentric, annular ejectors. An ejector configuration capable of simultaneously augmenting and deflecting the thrust of a jet engine downward for VTOL is discussed, as is a proposed jet flap scheme wherein the jet flap effects would be greatly augmented during STOL by an ejector device at the wing trailing edge.

The technology of ejectors using multiple diverging sheets of primary air is in its infancy. The projects described were based on results already achieved but which fall short of theoretical predictions and will undoubtedly be improved with further research and development.

Presently, ejector lift systems offer three significant advantages relative to auxiliary lift engines:

1. They achieve lower fuel consumption in both hover and cruise.
2. Noise is reduced by greater than 10 db in hovering flight.
3. They reduce the destructive effects of jets on the ground as a result of relatively low downwash velocity.

"Contribution Au Development Des Tromps Et Ejecteurs", Reference 3-2

A theoretical treatment of the Bertin ejector is shown, completely written in French. It discusses in further detail the ejectors discussed in Reference 3-1.

"Helicopter with Jet Reaction for Counteracting Torque", Reference 3-3

A patent is described for an internal blower, located in the fuselage, which is turbine driven by main engine exhaust gases and drives engine cooling air exhaust and main engine exhaust gases to nozzles in the tail.

The invention claims maximum use of waste energy to obtain a high energy gas and air supply to the nozzles. However, from a heat balance standpoint, it appears that a good part of the engine exhaust energy will be in the downstream mixture of cooling air and turbine exhaust to counteract rotor torque. Figure 49, illustrates the concept.

"Helicopter with Anti-Torque Tail Jet", Reference 3-4

An invention is shown which uses a tail jet to counteract rotor torque.

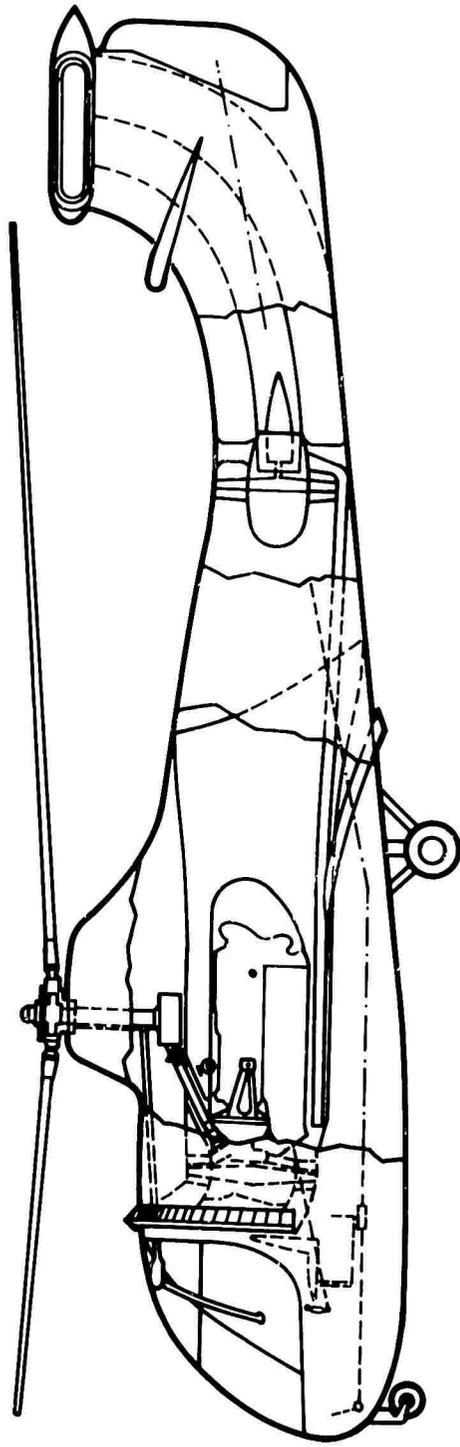


Figure 49. Helicopter With Jet Reaction for Counteracting Torque, Pat. No. 2,503,172.

The energy for the jet is supplied by air ejector pumps mounted on the engine and using engine exhaust. An alternate arrangement has an air source produced by a power blower located in the engine compartment. Auxiliary air intakes are provided on the exterior surface of the fuselage in positions to permit the air to be drawn into the air duct.

The engine jet air pumps would contribute a relatively small percentage of the total mass air/gas flow required. The large blower version improves this condition. Figure 50 illustrates the concept.

"Helicopter with Anti-Torque Reaction Jet", Reference 3-5

The invention is shown which uses a direction-adjustable reaction jet to counteract main rotor torque. This jet is energized through an air/gas duct which connects the jet nozzle and the air/gas blower. The blower uses the engine exhaust gases plus ambient air. Figure 51 illustrates this concept.

"Torque-Compensation Apparatus for Helicopters," Reference 3-6

An invention is reported which provides an auxiliary two-nozzle system to be used as a redundant back-up for the tail rotor system. It uses a tank of pressurized gas as an energy source with solenoid valve actuation. It also implies a dubious alternate energy source from a turbine engine exhaust. Figure 52 illustrates this concept.

"Air Coupling System for Helicopters", Reference 3-7

A scheme is reported which employs a large centrally located powered fan in the fuselage. By a system of large ducts in the fuselage, the fan drives a turbine that drives the main rotor and provides an air source for a tail jet anti-torque control. Since the turbine turns at main rotor rpm, the low tip speed would result in very low turbine efficiency. Figure 53 illustrates this concept.

"Improvements to Rotary-Wing Aircraft", Reference 3-8

A scheme is reported which directs exhaust gas from the main turbine engine to a tail nozzle system that has a rearward directed nozzle and a laterally directed nozzle. Internal adjustable vanes can direct the gas wholly through one nozzle or the other or in varying proportions through both outlets simultaneously. An external airspeed sensing device reduces the anti-torque action with increasing forward speed. Figure 54 illustrates this concept.

"Yaw and Thrust Control," Reference 3-9

An axial-flow compressor supplies high pressure air to an aft fuselage plenum duct. Air is jet released from both sides of the aft fuselage to outside atmosphere through a modulating nozzle system providing instant response by simultaneously reducing thrust on one side and increasing it on

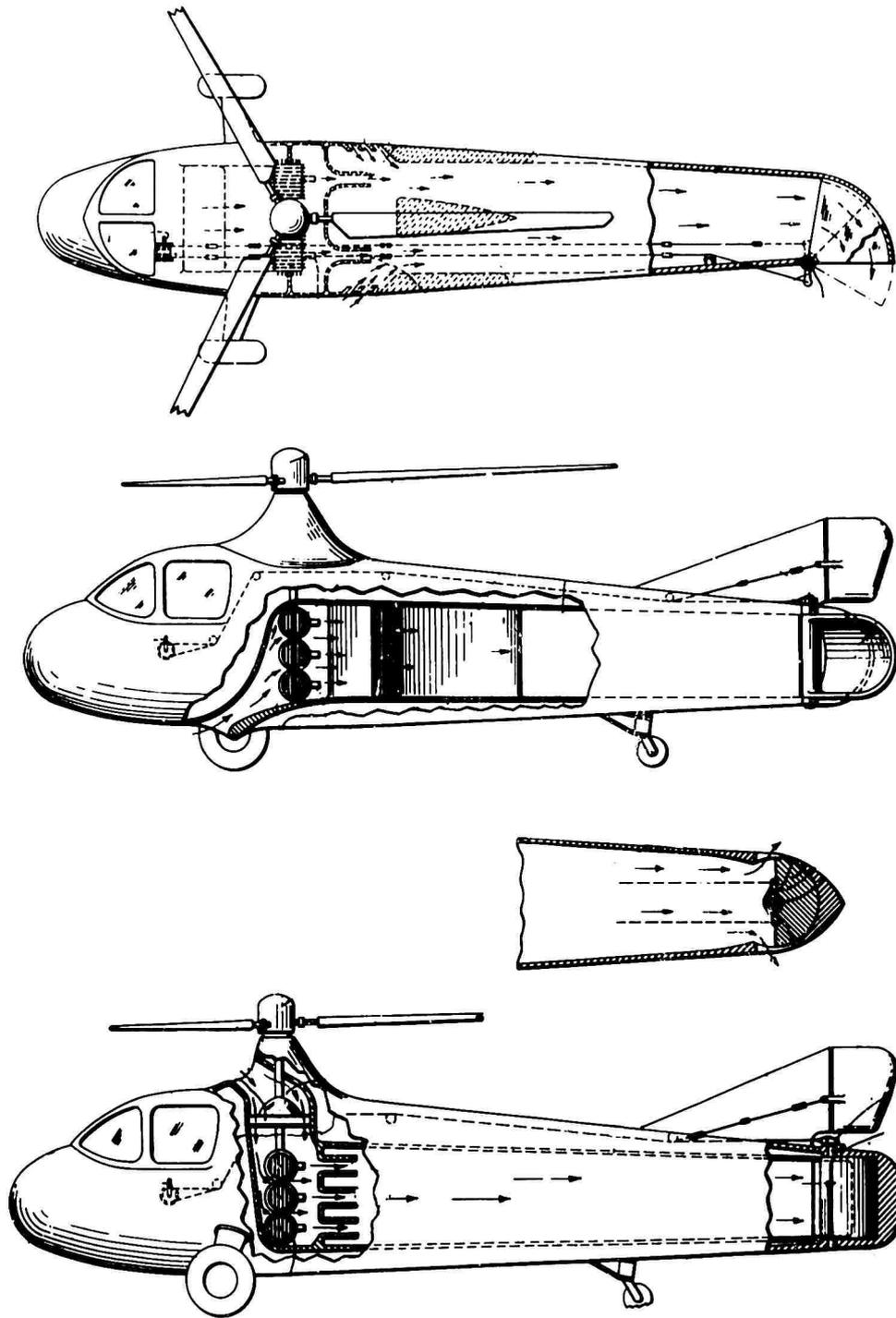


Figure 50. Helicopter With Anti-Torque Tail Jet,
Pat. No. 2,518,697.

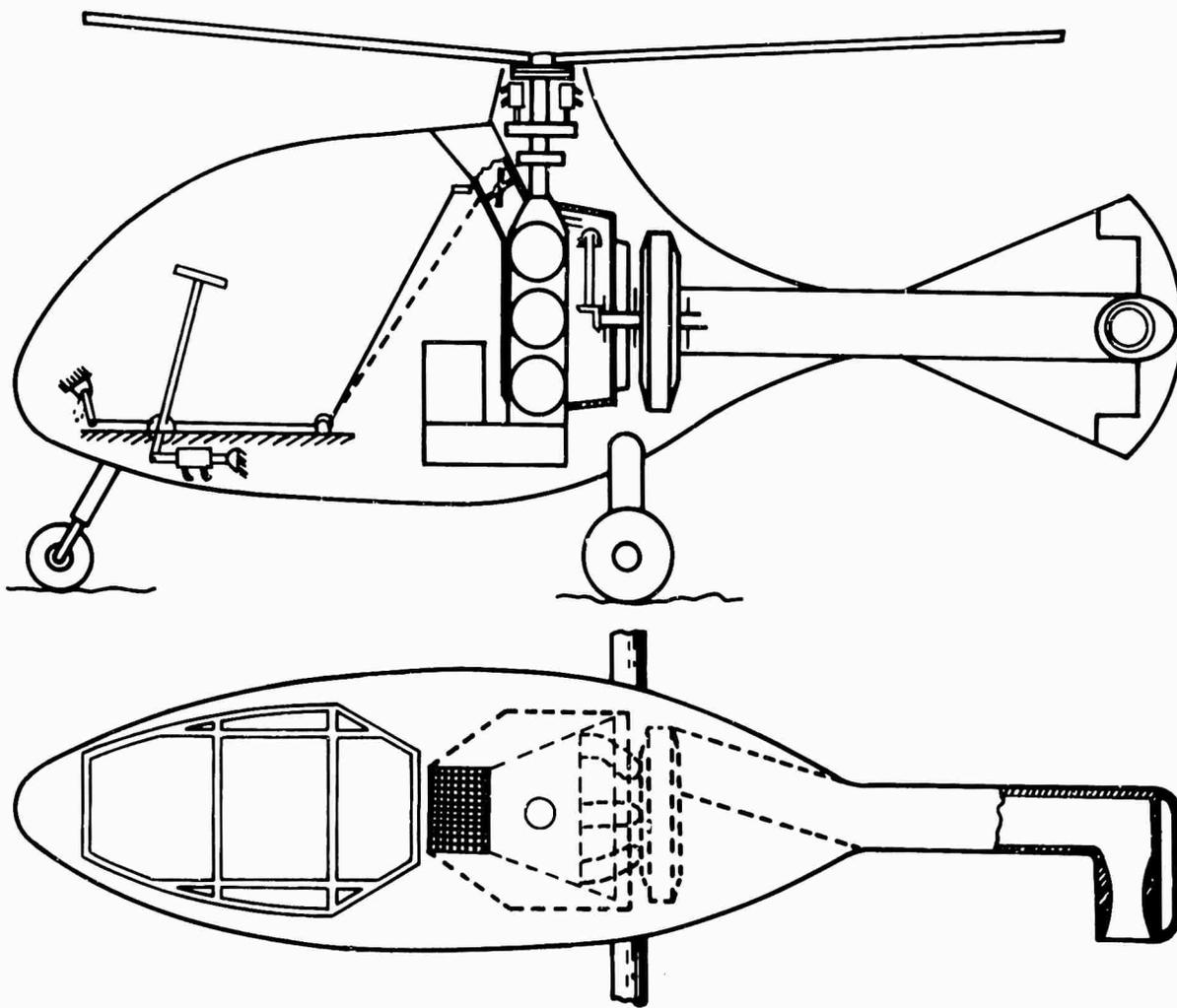


Figure 51. Helicopter With Anti-Torque Reaction Jet, Pat. No. 2,486,272.

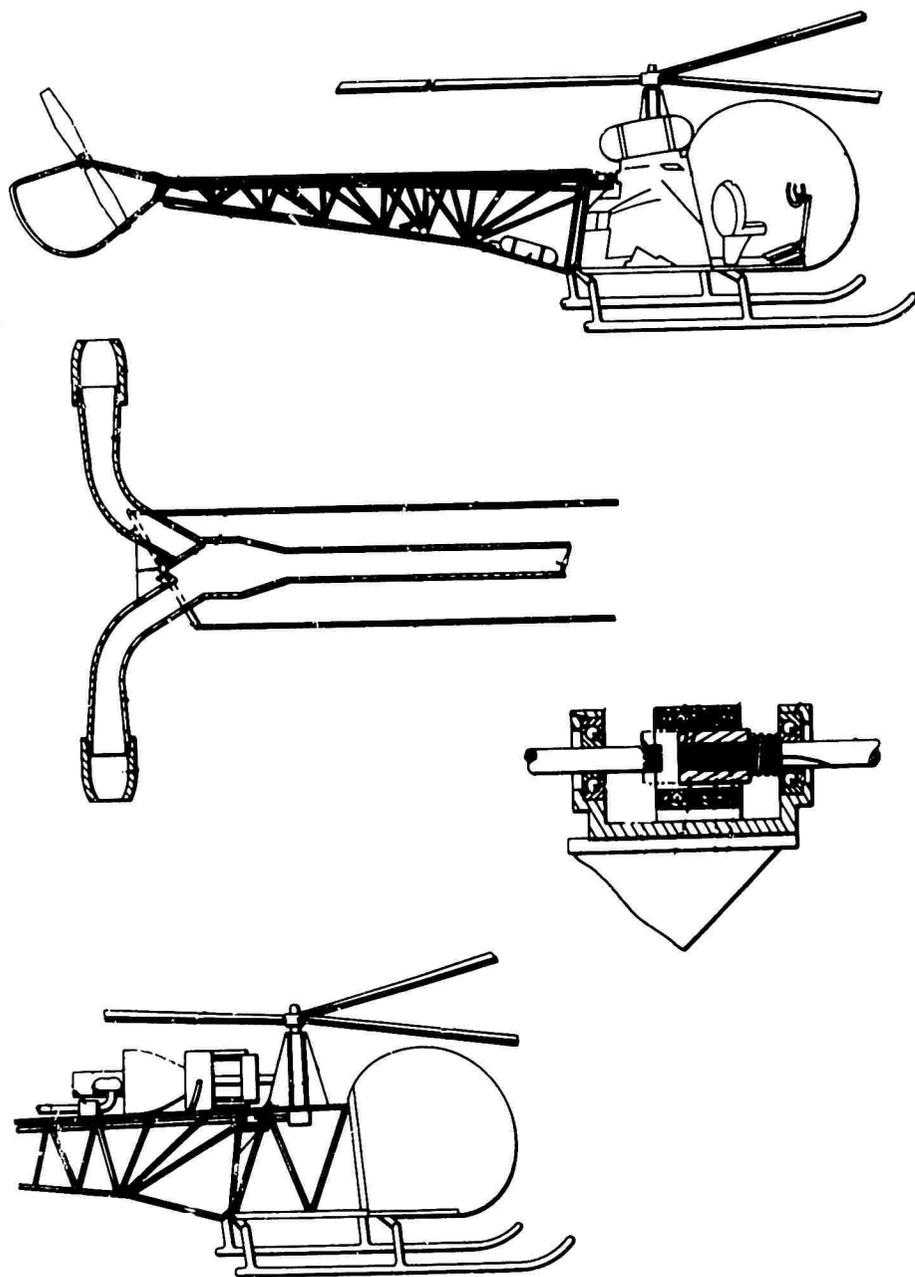


Figure 52. Torque-Compensation Apparatus for Helicopters,
Pat. No. 3,199,302.

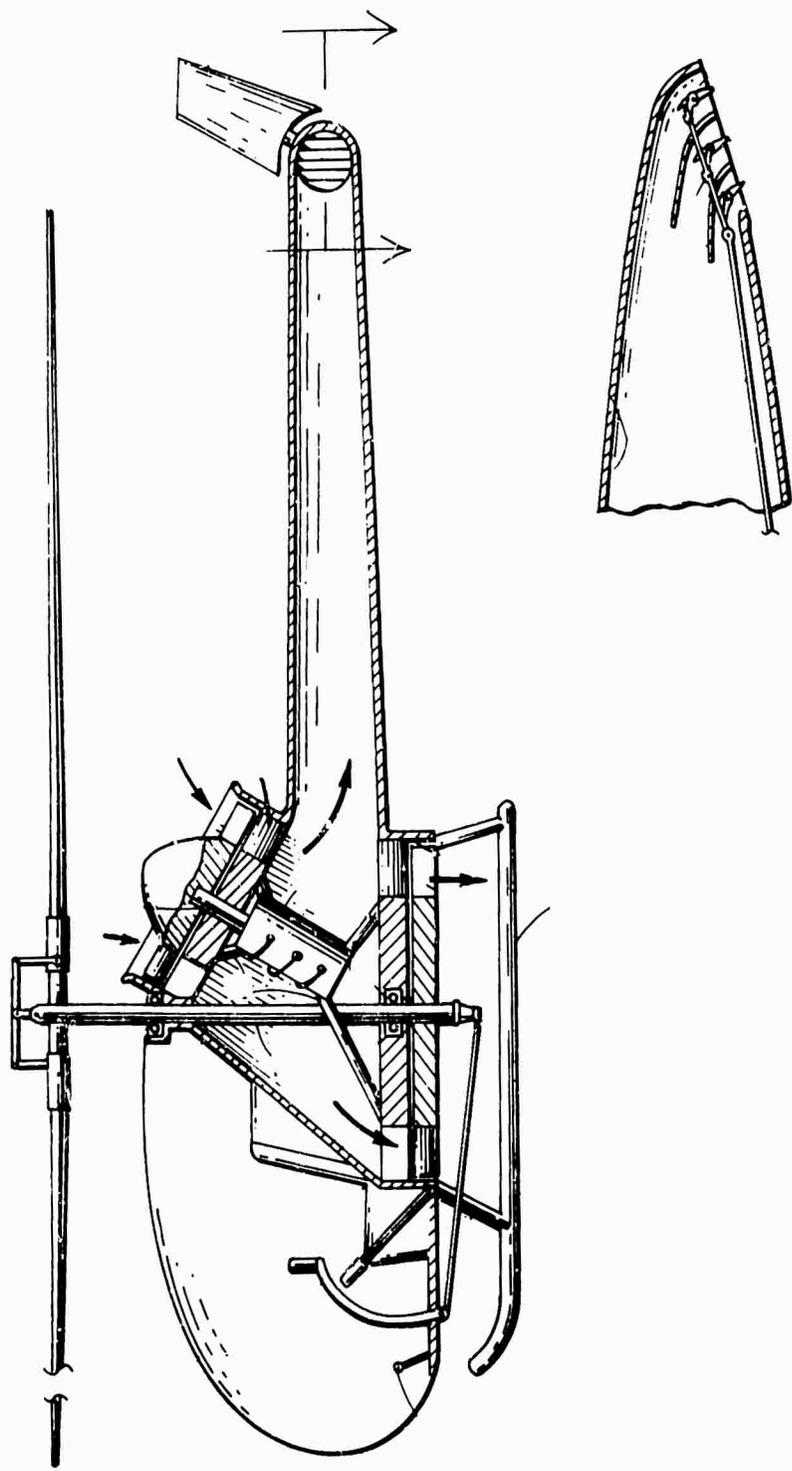


Figure 53. Air Coupling System for Helicopters, Pat. No. 3,510,087.

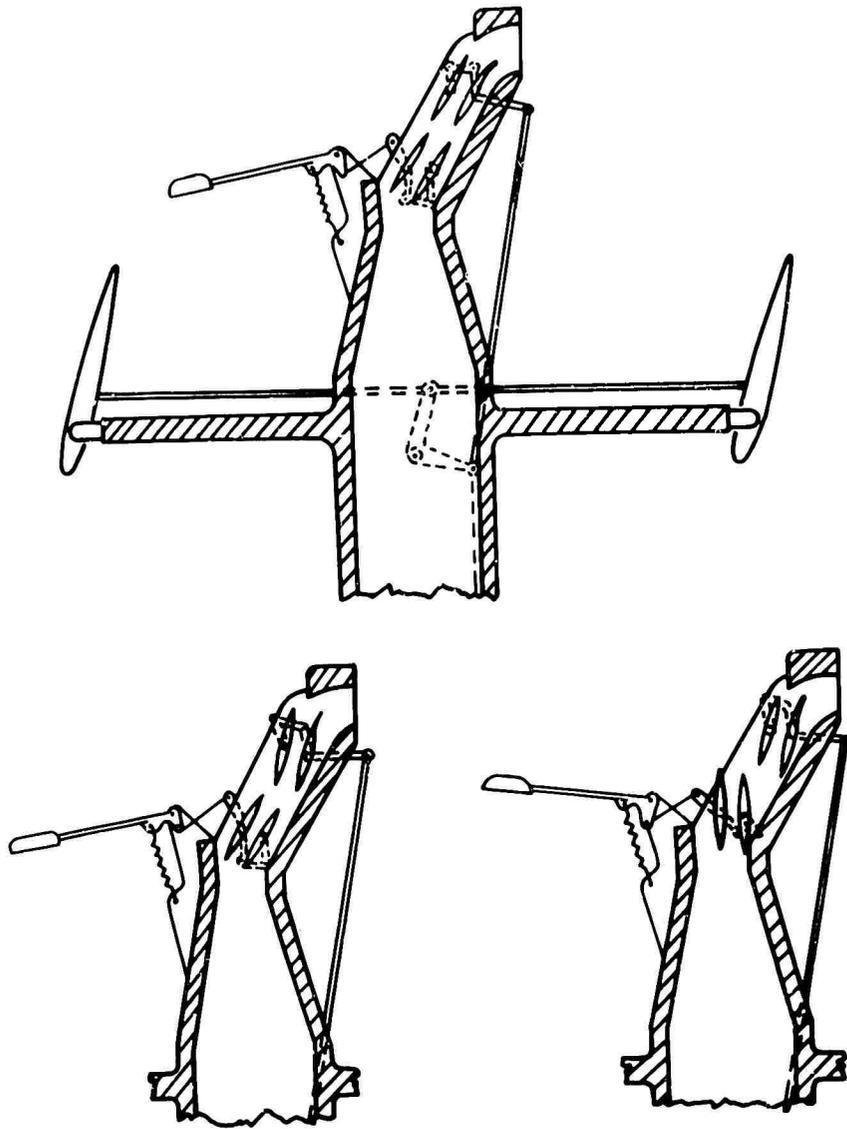


Figure 54. Improvements in Rotary-Wing Aircraft, British Pat. No. 818,358.

the other side. The compressor is shaft driven from the main rotor gearbox. Figure 55 illustrates this concept.

"Aircraft Yaw Control", Reference 3-10

A compressor supplies high pressure air to an aft fuselage plenum. Air is jet released to atmosphere through a rotatable nozzle. The nozzle position is controlled by the gyroscopic forces of the turbine compressor through a linkage assembly. The compressor is shaft driven from the main gearbox and draws in main rotor downwash air. Figure 56 illustrates this concept.

"Exhaust Operated Torque Reactor for Helicopters", Reference 3-11

In this concept, an anti-torque force is obtained by lateral deflection of the turbine engine exhaust. Without unduly penalizing the main engine power, the anti-torque force would be inadequate. Figure 57 shows this concept.

"Automatic Control System for Rotating Wing Aircraft", Reference 3-12

Included in this patent is a device for counteracting rotor torque by ejecting a mass flow of air out the aft end of the fuselage through a series of adjustable louvers. The air flow is produced by a large internally installed propeller powered by the rotor engine. Figure 58 illustrates this concept.

"Reaction Jet Torque Compensation for Helicopters", Reference 3-13

This invention incorporates an air or gas jet whose discharge is directed from the tail of the fuselage in the proper direction to compensate for the torque reaction. This jet is directed through the tunnel-shaped fuselage so that the fan generating the air jet is closely adjacent to the power plant and, in addition to furnishing the air jet, also serves as a means of drawing cooling air over the engine. Figure 59 illustrates this concept.

"Yaw Control System", Reference 3-14

This patent discloses a yaw control concept based on a deflected exhaust gas jet. The system is envisioned for a helicopter powered by a turbine engine. The exhaust nozzle of the engine is swivel mounted to direct the gases onto a deflector bucket, and this produces yaw moments for directional control. For high-speed flight, the deflector buckets are opened and the jet gases provide additional thrust in forward flight. Conventional control surfaces are used for high-speed directional control. This concept is shown in Figure 60.

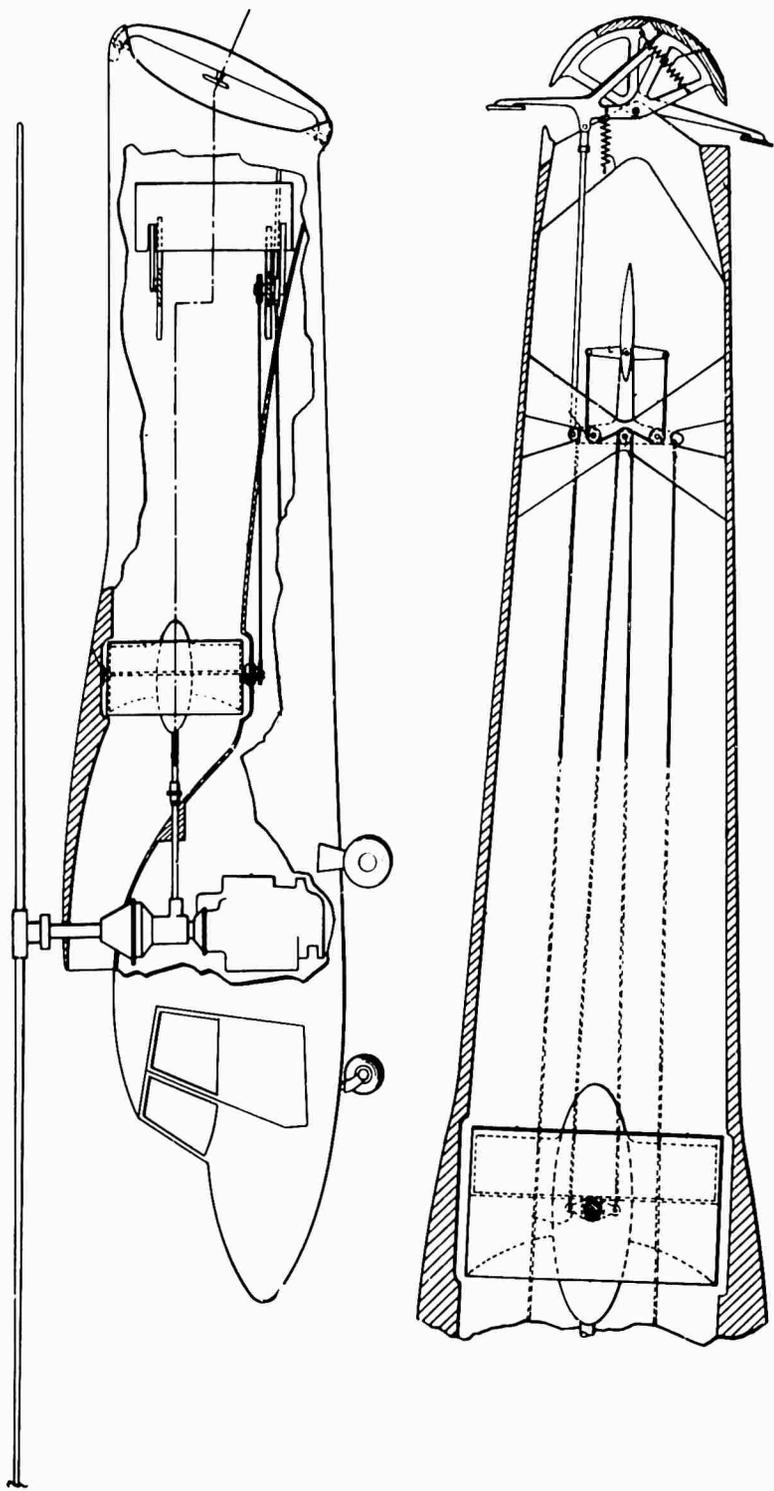


Figure 55. Yaw and Thrust Control, Pat. No. 3,026,068.

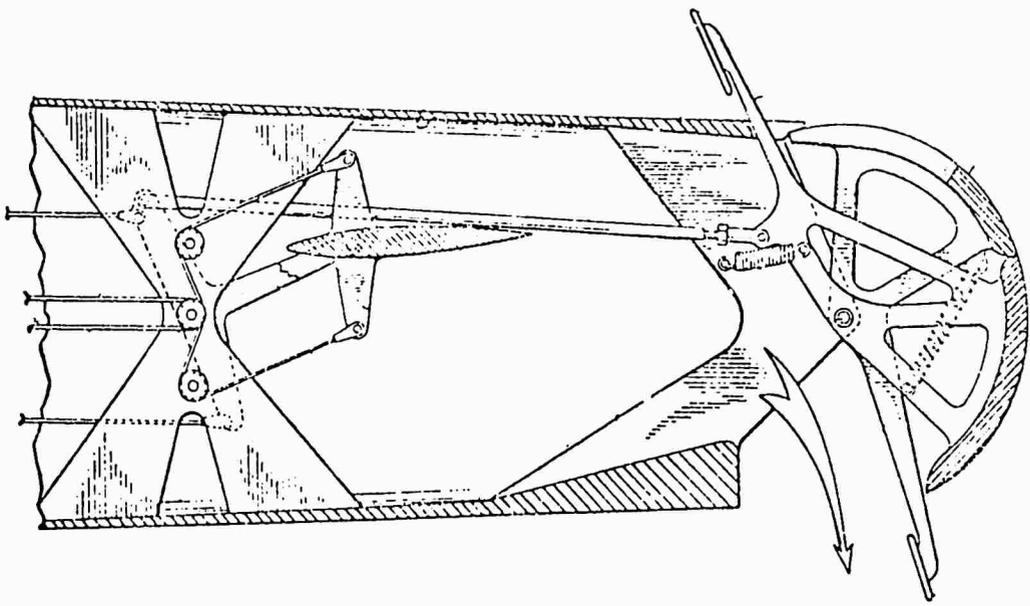
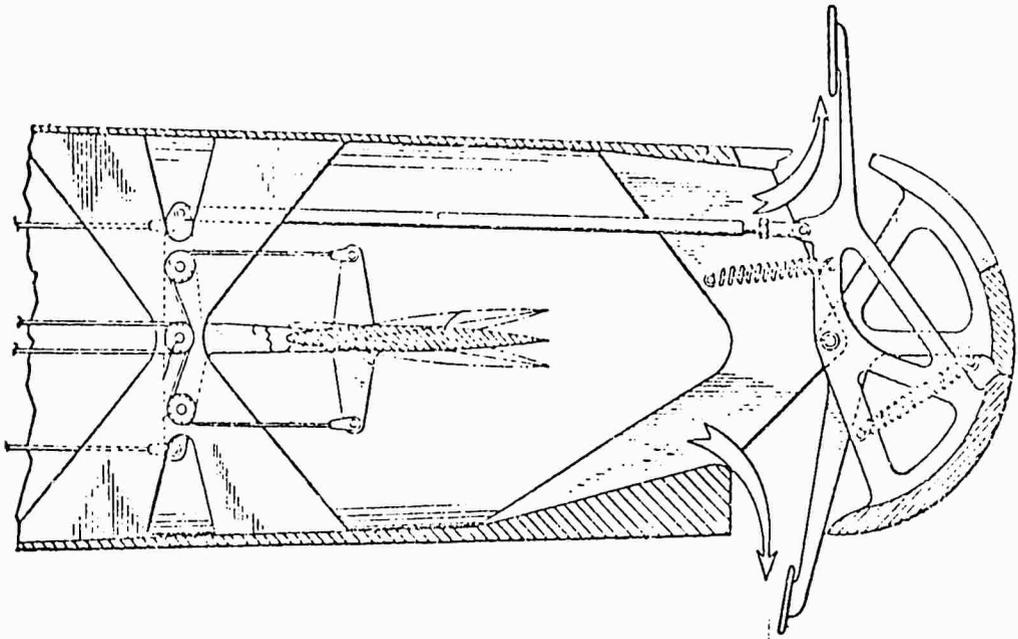


Figure 55. Continued

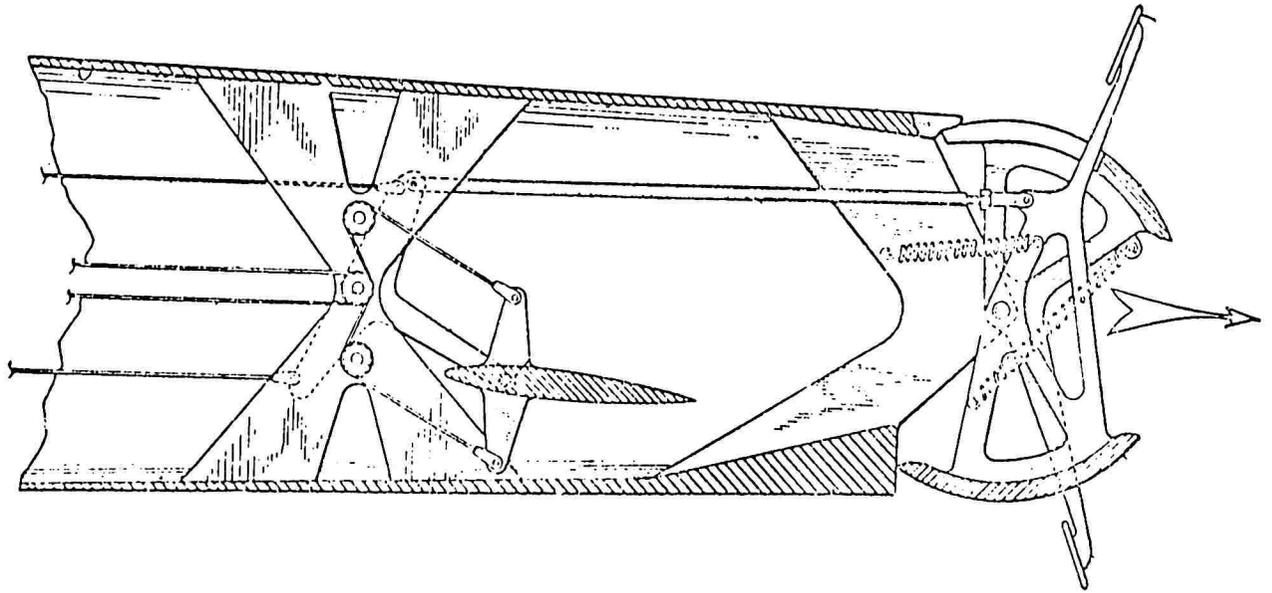


Figure 55. Continued.

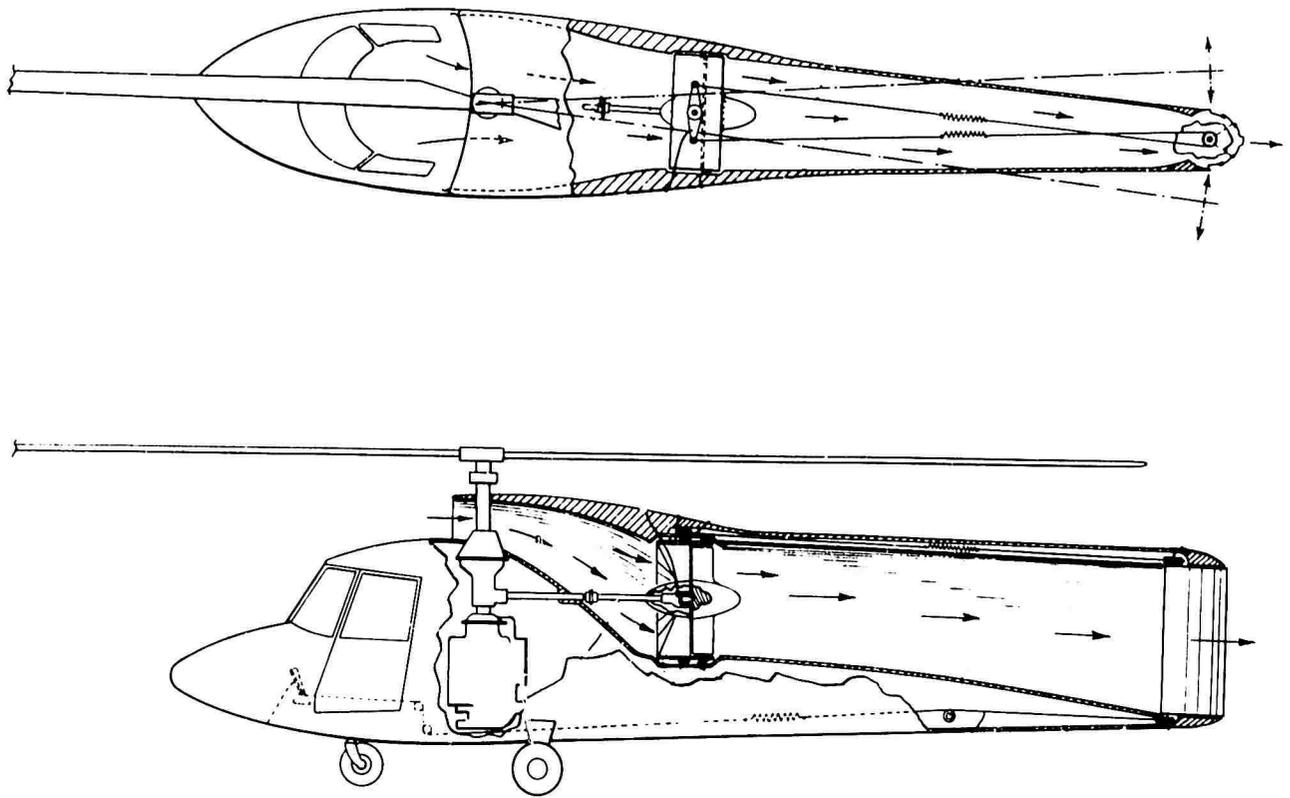


Figure 56. Aircraft Yaw Control, Pat. No. 3,015,460.

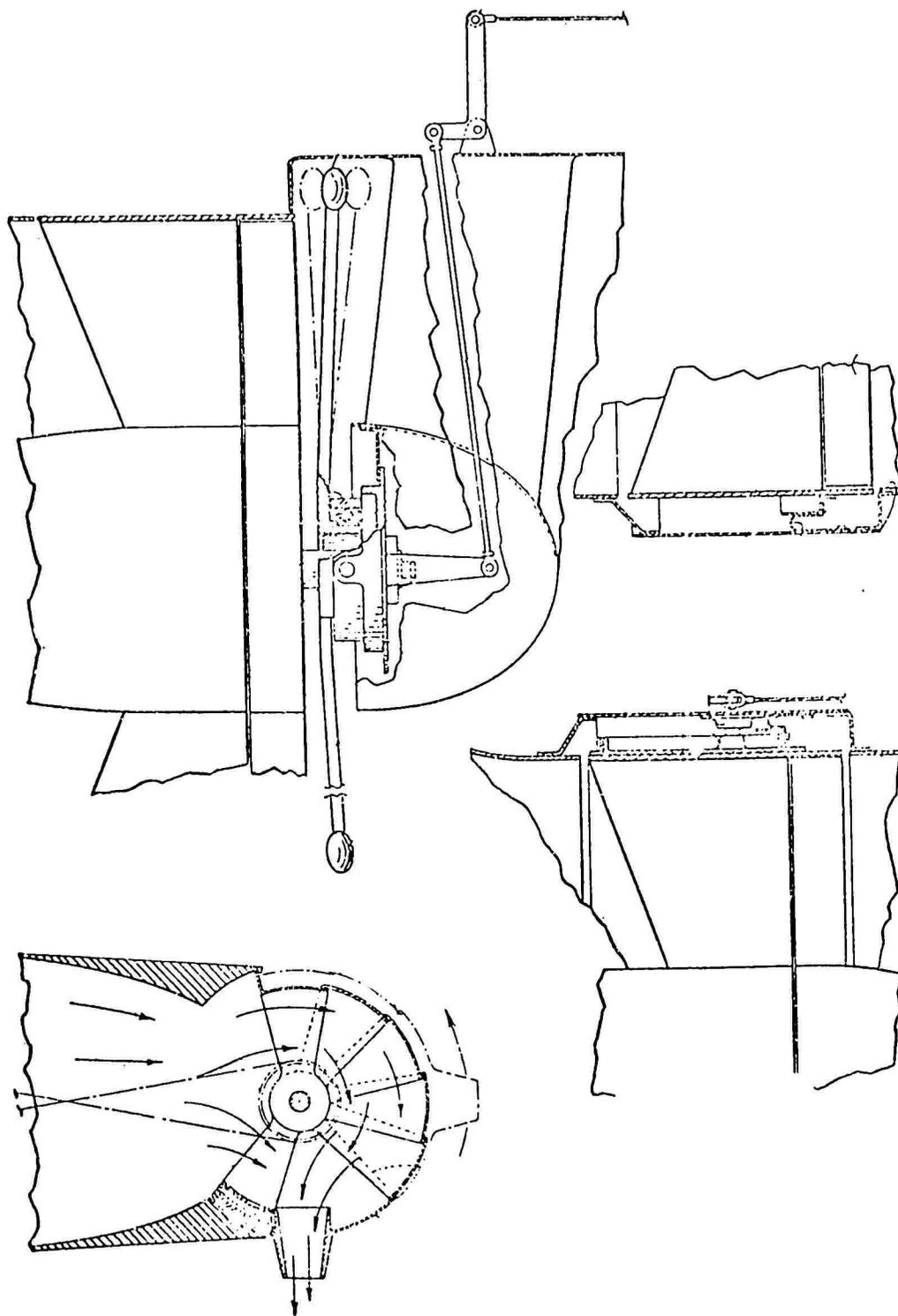


Figure 56. Continued

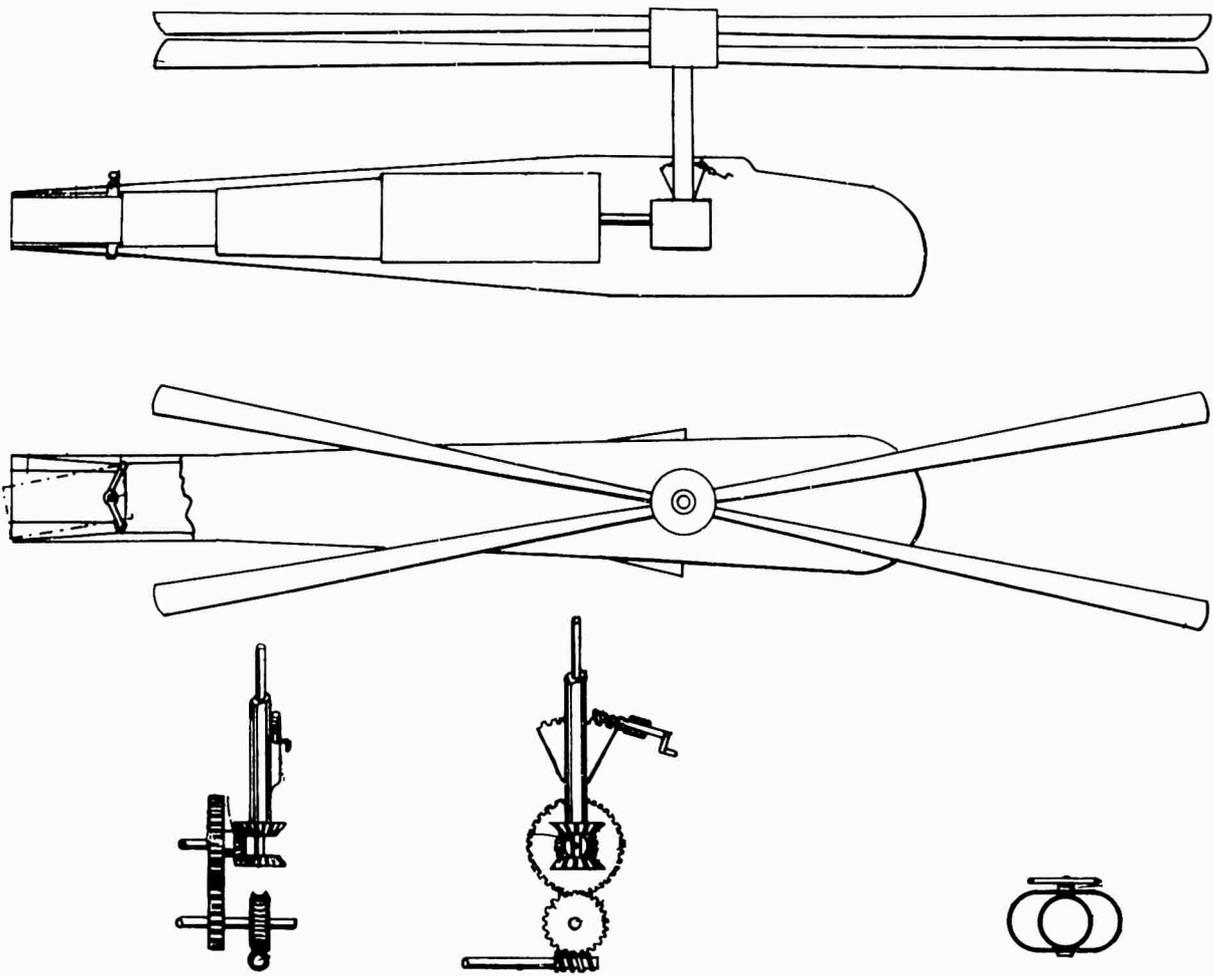


Figure 57. Exhaust Operated Torque Reactor for Helicopters,
Pat. No. 2,991,962.

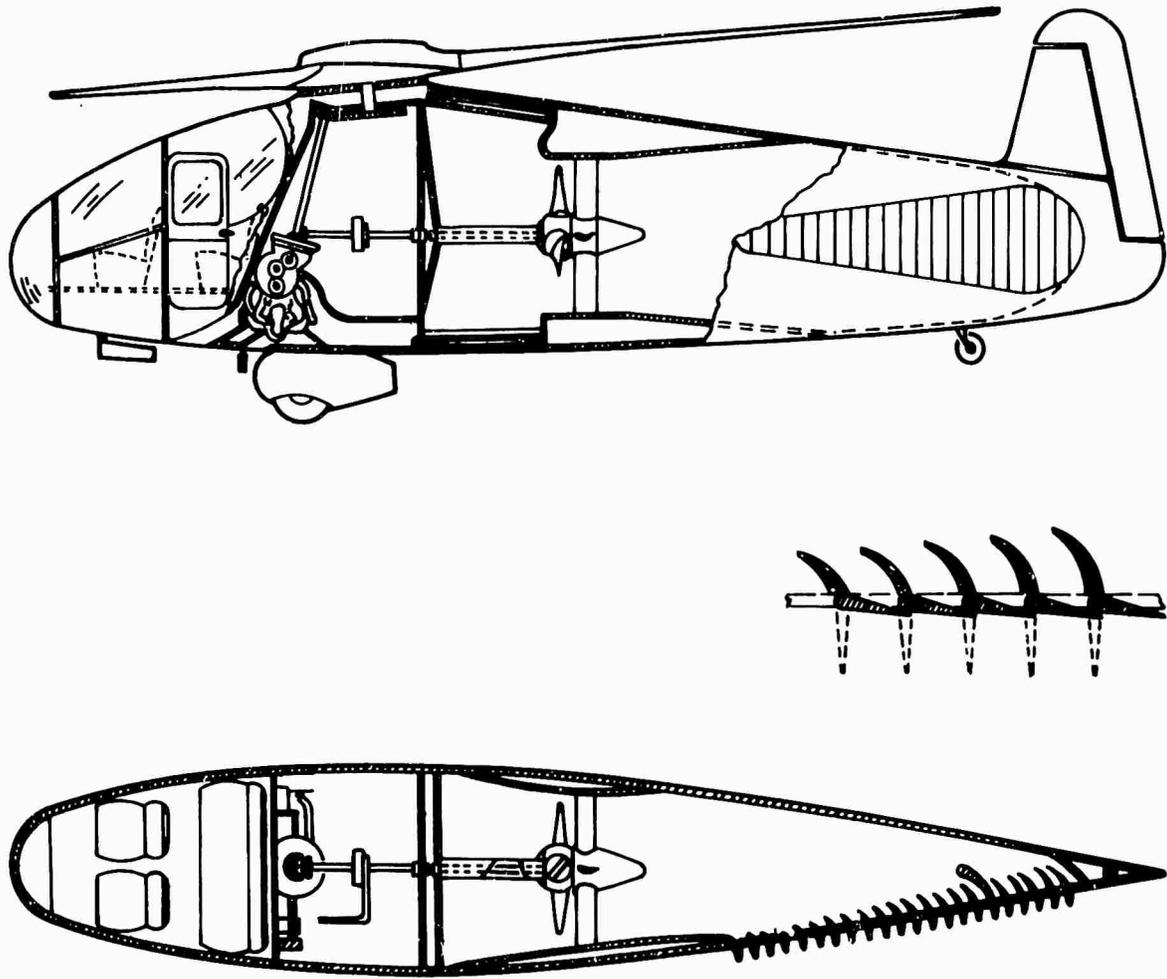


Figure 58. Automatic Control System for Rotating-Wing Aircraft,
Pat. No. 2,731,215.

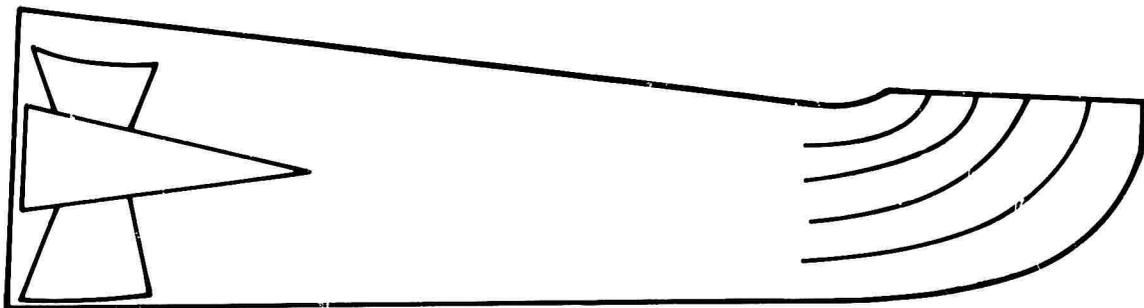
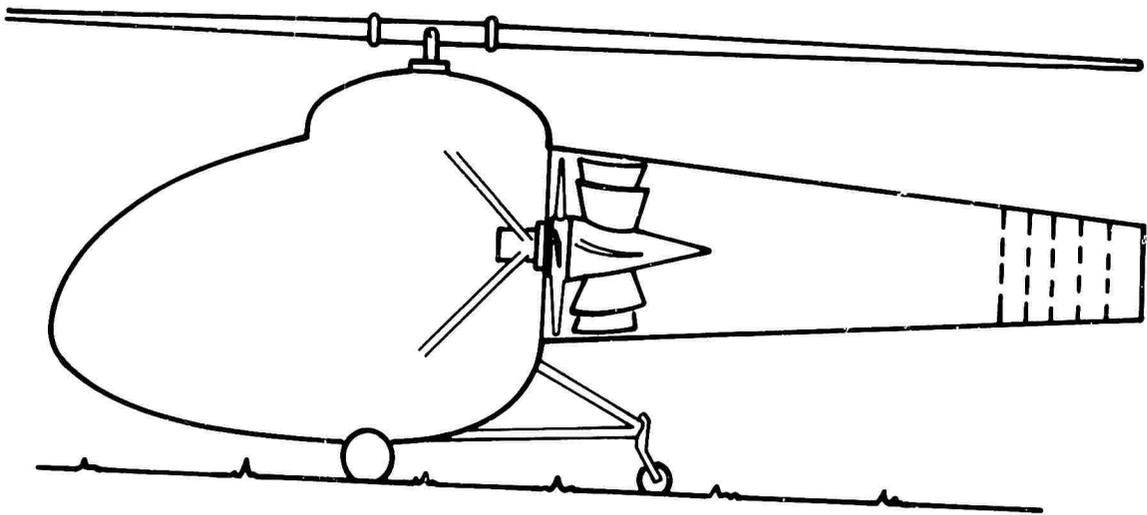


Figure 59. Reaction Jet Torque Compensation for Helicopter,
Patent No. 2,481,749.

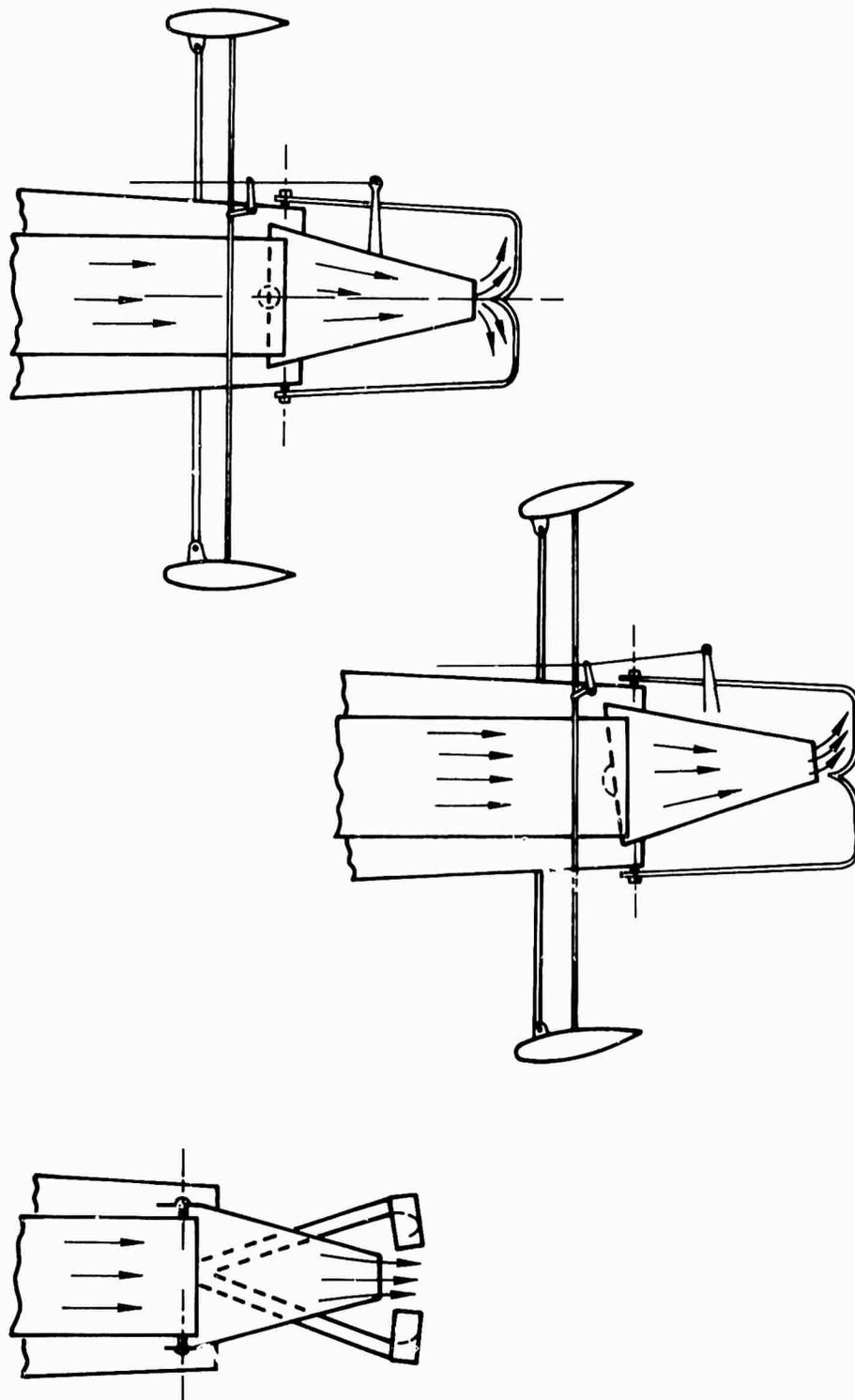


Figure 60. Improvements in Rotary-Wing Aircraft, British Patent No. 829,183

4. IMMERSED AERODYNAMIC SURFACES

"Deflected Slipstream Anti-torque System," Reference 4-1

A system in which a force for anti-torque is produced by deflecting the slipstream of an aft-mounted propeller was studied by Lockheed and a prototype was built and tested. Results of the tests showed that even with the best configuration that could be developed during an extensive wind tunnel program, the power necessary to produce the required anti-torque force was approximately 40 percent greater than if the force had been produced by a tail rotor.

It was also found that the ability to produce an anti-torque force during simulated rearward flight was drastically reduced. At a rearward speed of 40 knots, the system becomes totally ineffective.

"Torque Control for Helicopters," Reference 4-2

This concept is proposed to provide a torque compensating rotor which will not be hazardous to those in its immediate vicinity. It is constructed and operates as a Flettner rotor, immersed in the main rotor downwash.

A Flettner rotor uses the principle of the Magnus effect. According to the Magnus principle, a cylindrical body rotating in a stream of air will create a higher pressure on one side where the surface of the body rotates against the direction of movement of the air, and a lower pressure diametrically opposed to the high-pressure side. This Magnus effect produces a force tending to move the rotating cylinder crosswise to the moving stream of air.

By varying the speed of rotation of the cylinder, the value of the force produced can likewise be varied. Rotors of this type can develop lift coefficients as high as 10. However, the induced drag can be quite high. Furthermore, the rotating end plates shown in the referenced patent to minimize end losses could present a serious mechanical problem and a possible personnel hazard. Calculations indicate that the size of the rotor to produce the total required force would be excessive. Rotation reversal would be required for change in force direction, and no control is available for power-off autorotation. Figure 61 shows the concept.

"Helicopter Anti-torque Device," Reference 4-3

This invention provides a helicopter anti-torque mechanism that uses a secondary flow of air to create a circulation about an aft section of the fuselage. The downwash from the main rotor induces an aerodynamic side force which opposes the torque reaction of the main rotor.

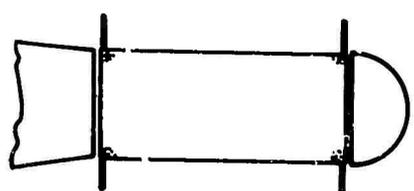
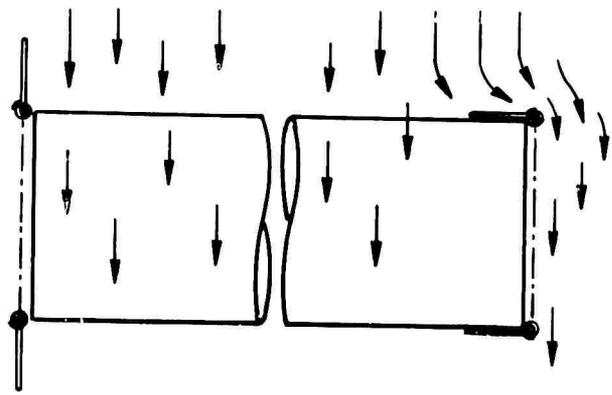
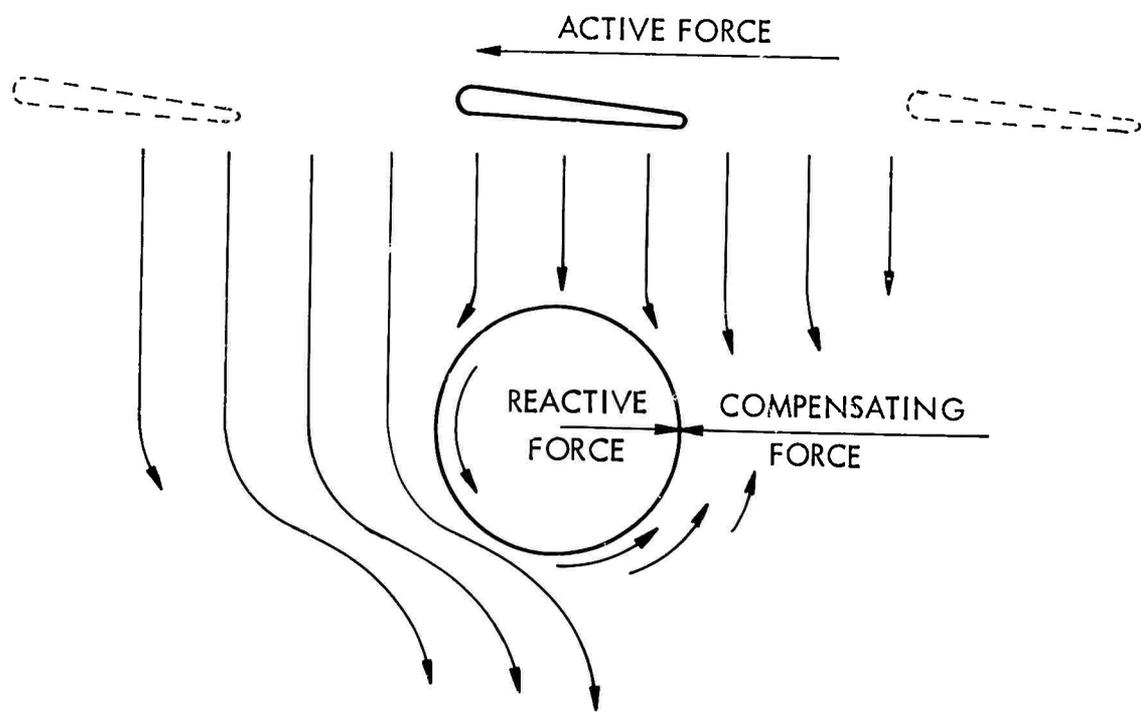


Figure 61. Torque Control for Helicopters, Pat. No. 2,452,355.

Further, this invention uses the exhaust flow from the power plant to drive the main rotor and, by controlling this flow, to vary the anti-torque forces produced by the mechanism of this invention.

It is felt that this device, in its present state, would not produce sufficient thrust to compensate for the torque produced by the main rotor. It may be considered advantageous to use this invention in conjunction with another directional control system. Figure 62 illustrates this concept.

"Helicopter," Reference 4-4

This patent uses a propeller to generate an air blast over the empennage to control the vehicle in azimuth, pitch, and roll. The rudder control would be used to negate the torque generated by the main rotor.

This concept requires considerable power to counter the main rotor torque. It is adversely affected by side or tail winds. Figure 63 illustrates this concept.

"Helicopter," Reference 4-5

This invention incorporates a high-rotational-speed rotor to minimize torque to drive the rotor. This torque is reacted by shaping the fuselage to conform with effective "angles of attack" to the rotor downwash. A sufficient countertorque may be aerodynamically imposed on it without the aid of other anti-torque devices.

This concept compromises an optimum rotor design in favor of low torque. It also compromises the fuselage shape for aerodynamic torque requirements. Figure 64 illustrates this concept.

"Anti-Torque Means for Helicopters," Reference 4-6

The anti-torque device incorporated in this invention consists of a vertical cambered rudder-type surface. This airfoil is placed in the exit of an air duct which is located within the fuselage. An air blower supplies air to the duct; the air exits flowing around the airfoil, thus generating a lift/force acting in an anti-torque direction.

This is a relatively inefficient method of transmitting and converting energy into a usable force. Figure 65 illustrates this concept.

"Rotary-Wing Aircraft Tail Assembly and Controls," Reference 4-7

A large tail ring structure concentric with fore and aft axis of the fuselage houses a propeller that drives air over a rudder which is integral with the tail ring. The tail ring is actually the empennage structure and as such also contains horizontal stabilizer surfaces. The propeller is driven by shaft power. Figure 66 illustrates this concept.

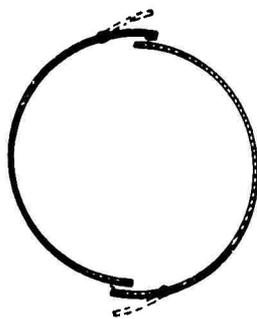
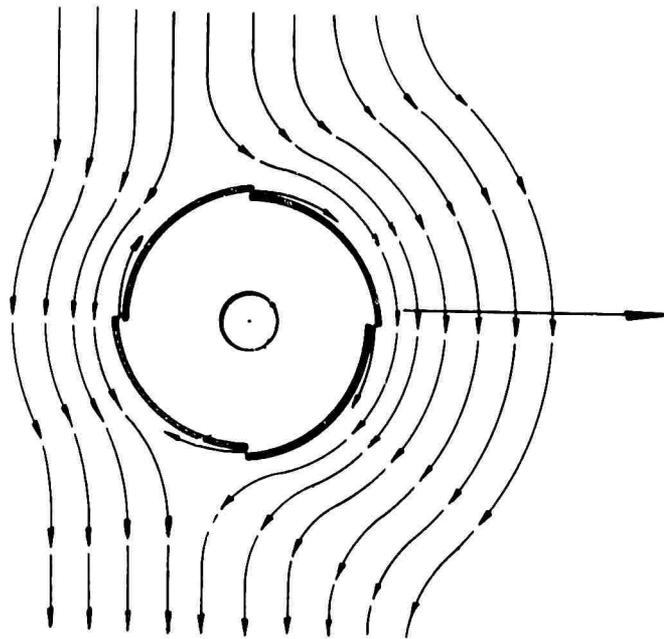
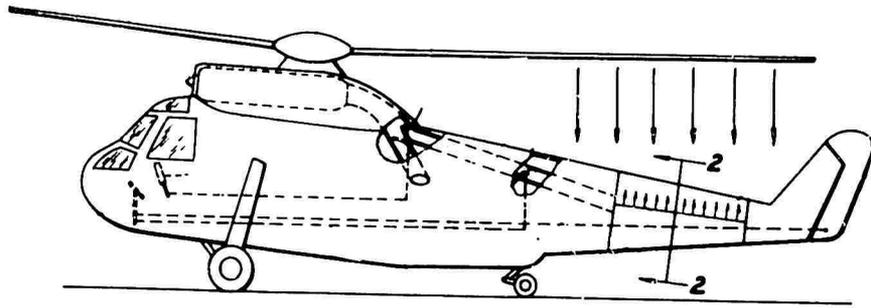


Figure 62. Helicopter Anti-torque Device, Pat. No. 3,059,877.

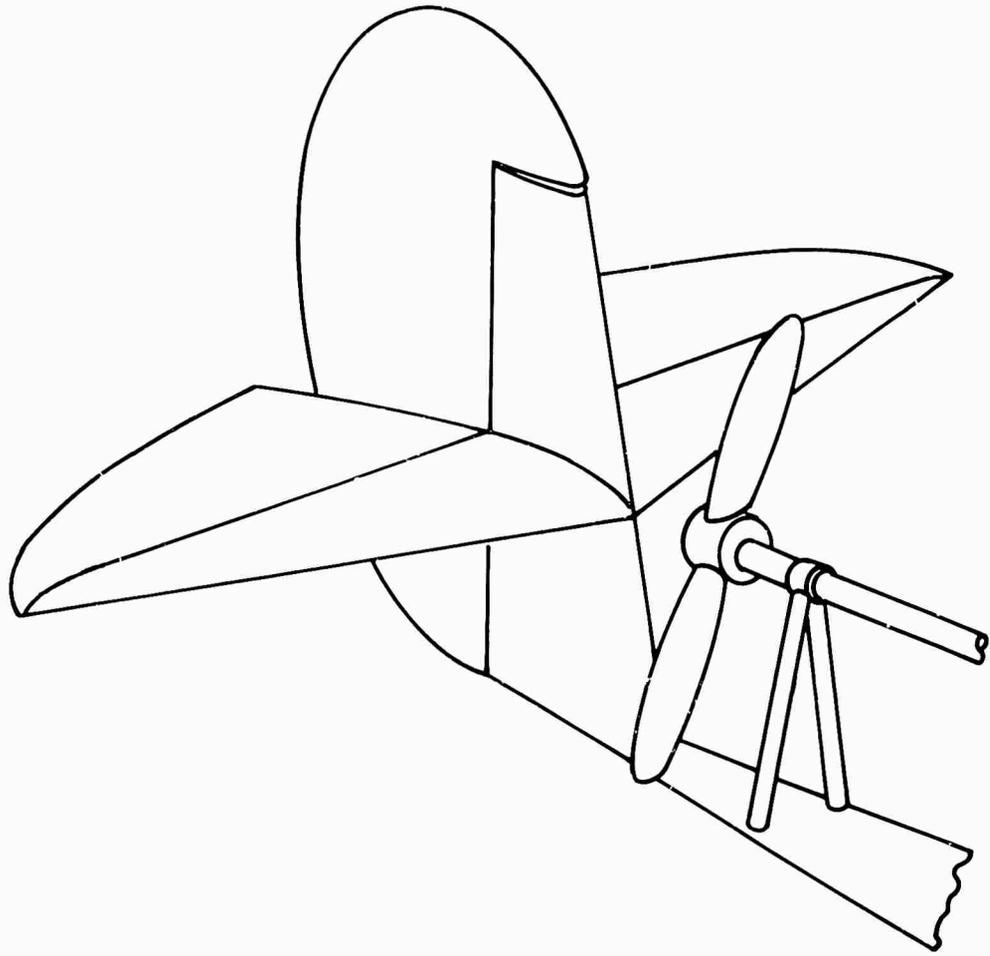


Figure 63. Helicopter, Pat. No. 3,029,048.

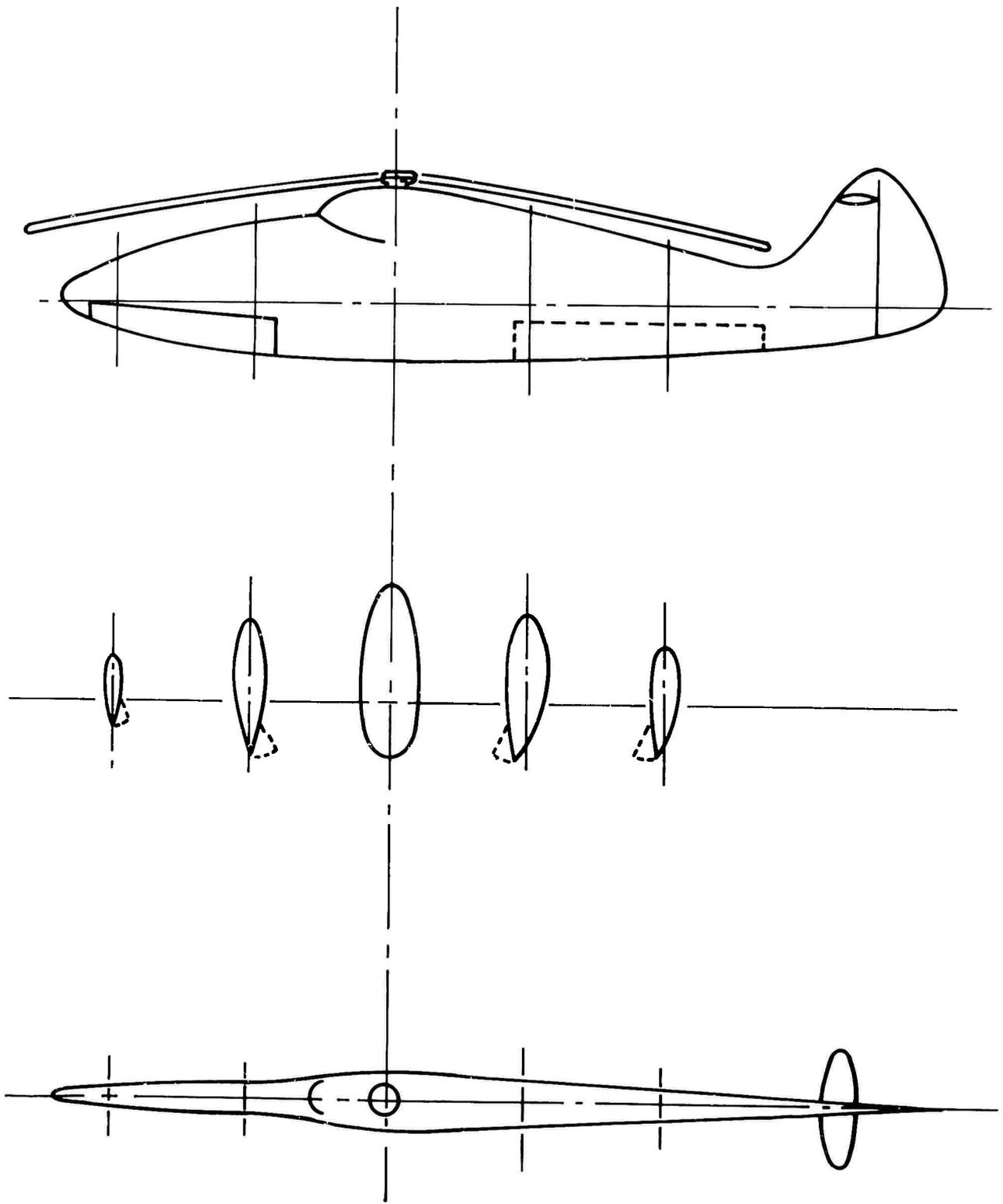


Figure 64. Helicopter, Pat. No. 2,338,935.

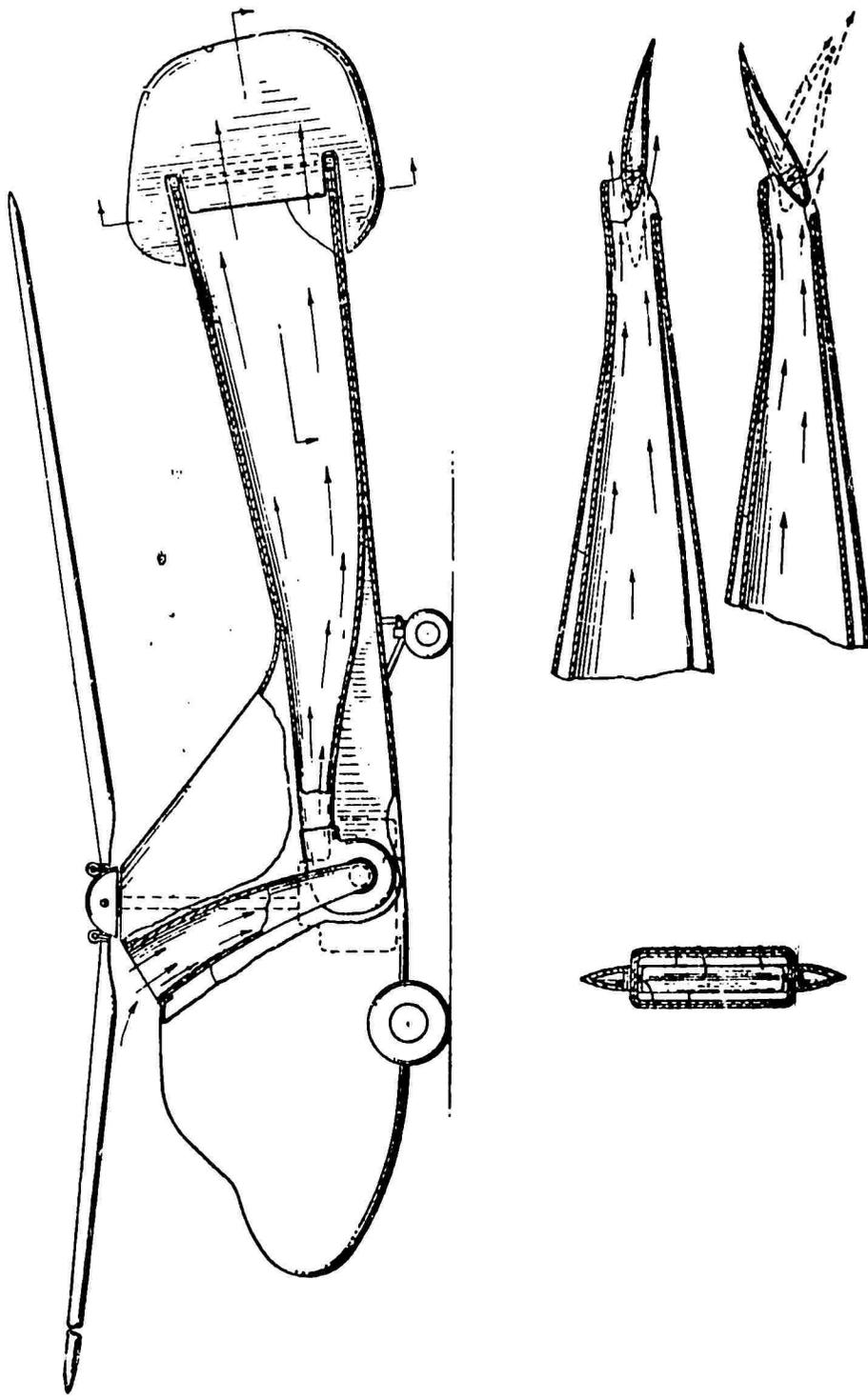


Figure 65. Anti-torque Means for Helicopters, Pat. No. 2,433,251.

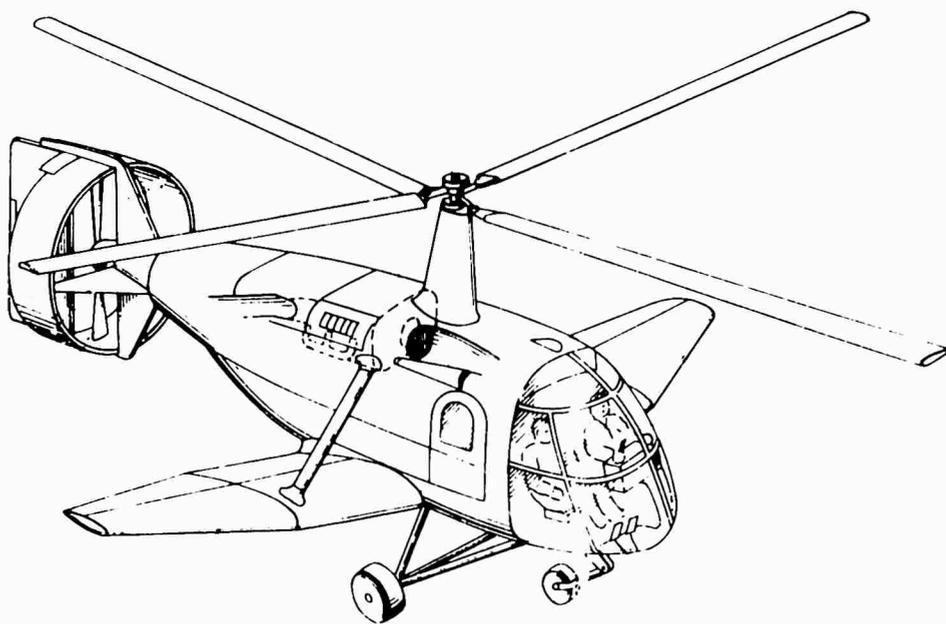


Figure 66. Rotary Wing Aircraft Tail Assembly and Controls,
Pat. No. 3,138,349.

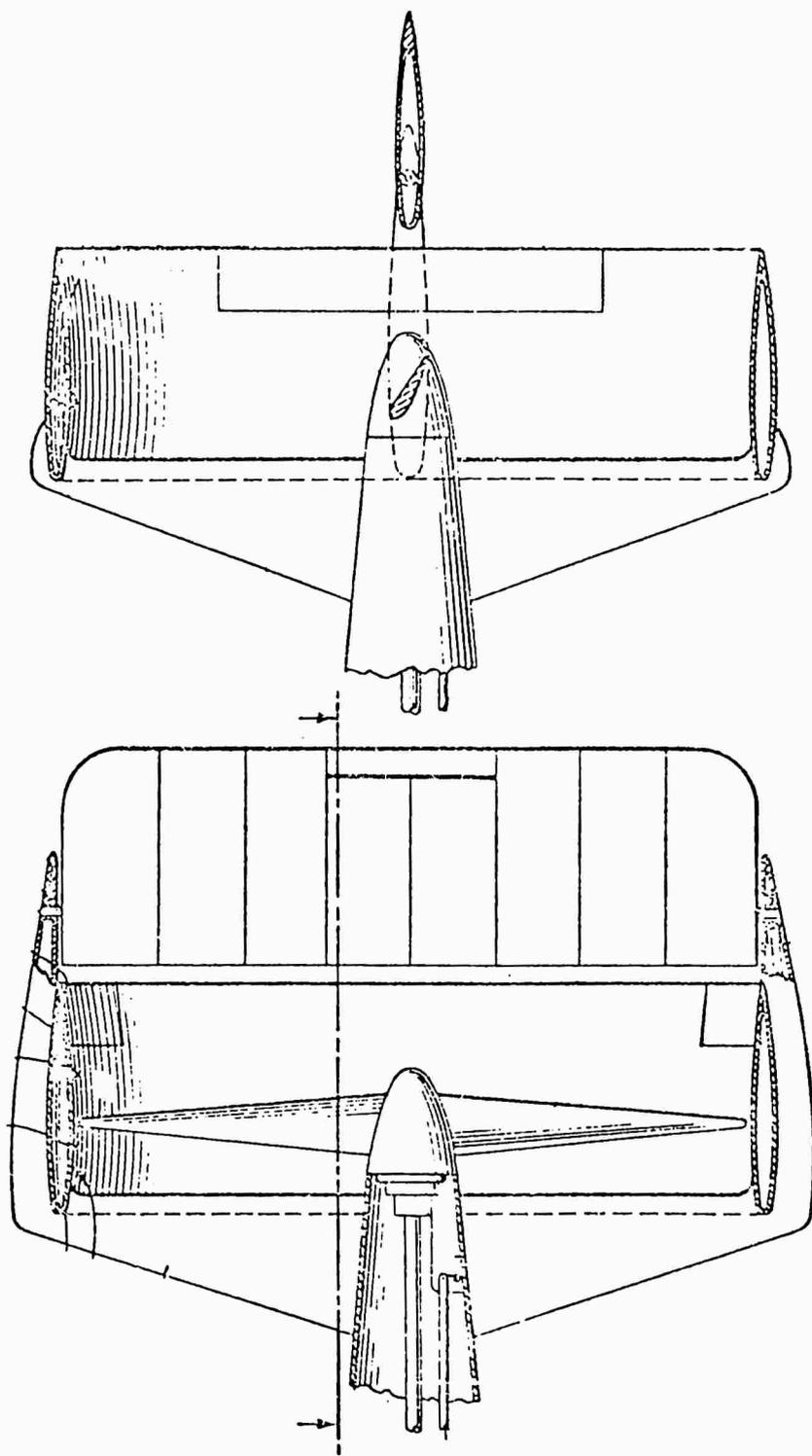


Figure 66. Continued.

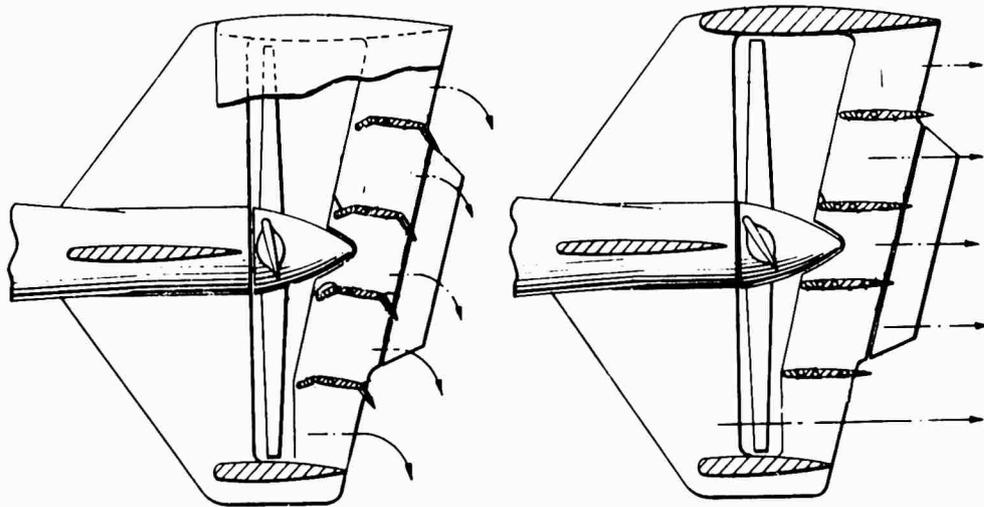
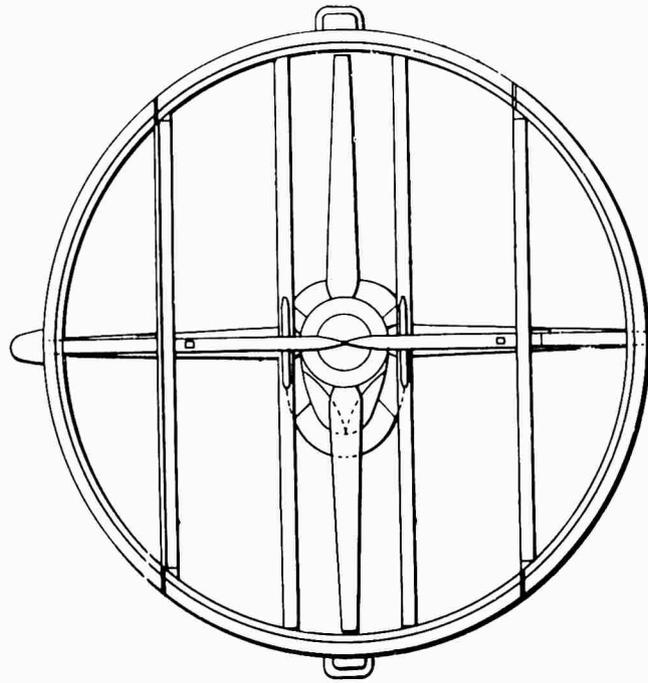


Figure 67. Slipstream Deflector Assembly for Aircraft,
Pat. No. 3,222,012.

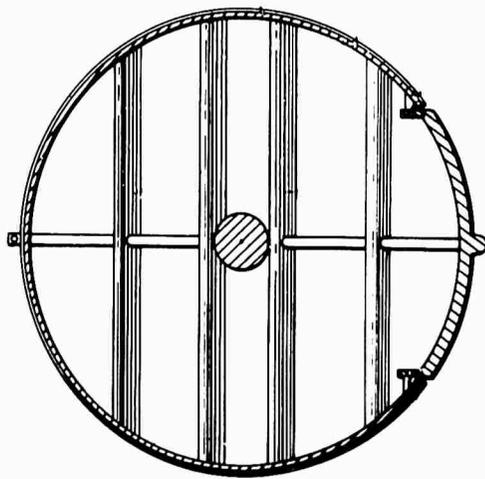
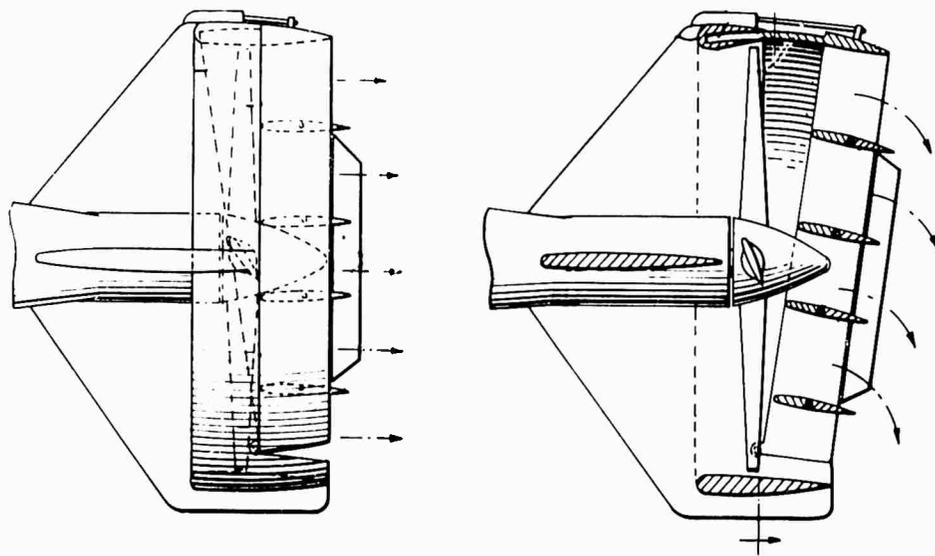


Figure 67. Continued

"Slipstream Deflector Assembly for Aircraft", Reference 4-8

This invention provides a mechanism to rotate an entire tail ring assembly similar to that described in Patent No. 3,138,349 (Figure 66) but differing from that patent by the use of multiple vanes instead of single surfaces. This provides a greater range of control for the tail ring device. Figure 67 illustrates this concept.

"Compound Helicopter with Shrouded Tail Propeller", Reference 4-9

This invention applies the tail rail ring for directional and anti-torque control as it does in Patent No. 3,138,349 (Figure 66) for a compound helicopter. It differs from Figure 67 in the use of single vertical and horizontal surfaces in lieu of cascades. Figure 68 illustrates this concept.

"Directional Control Assembly", Reference 4-10

This invention improves the assembly to facilitate maintenance characteristics of the concept shown in Figure 69.

"Helicopter Steering Surface Control", Reference 4-11

This invention related to helicopters of the type in which vanes located in the slipstream of a gondola-sustaining rotor are adjustable to intercept the slipstream at different angles, thereby imparting horizontal forces to the gondola and allowing directional control of the helicopter while it is in flight.

In order to offset the torque imparted to the gondola by the rotor, four generally rectangular blades extend horizontally outward through the walls of the gondola at equidistantly spaced points about its girth. The angle of interception of the blades with the rotor slipstream may be adjusted to offset changes in rotor torque.

Arranged outwardly of and in laterally spaced relation to the rectangular blades are rectangular vanes that provide directional control for the helicopter when in hovering flight. Control in forward flight is questionable and nonexistent in autorotation. Figure 70 illustrates this concept.

"Aircraft", Reference 4-12

This invention includes an arrangement of anti-torque surfaces or airfoils located in the slipstream of the rotor to counteract the torque reaction incident to the transmission of power from the fuselage to the rotor.

This is not considered a practicable concept. Figure 71 illustrates this concept.

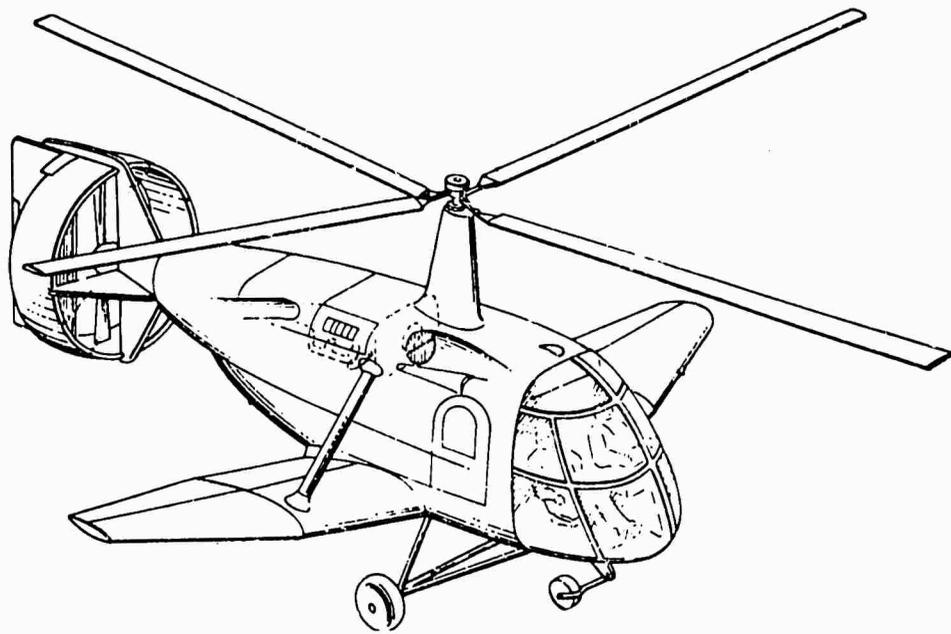
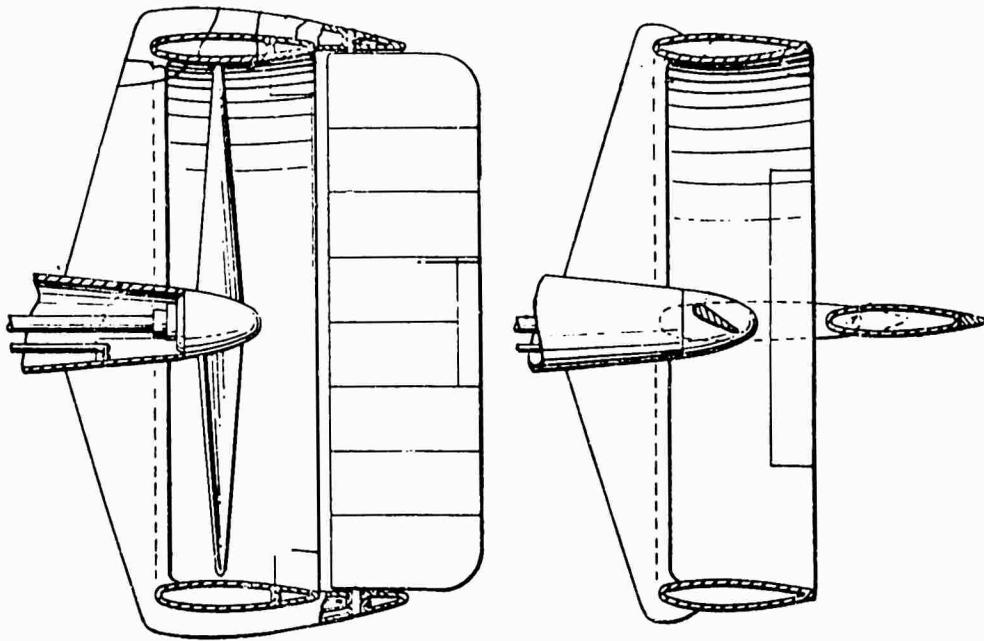


Figure 68. Compound Helicopter With Shrouded Tail Propeller,
Pat. No. 3,241,791.

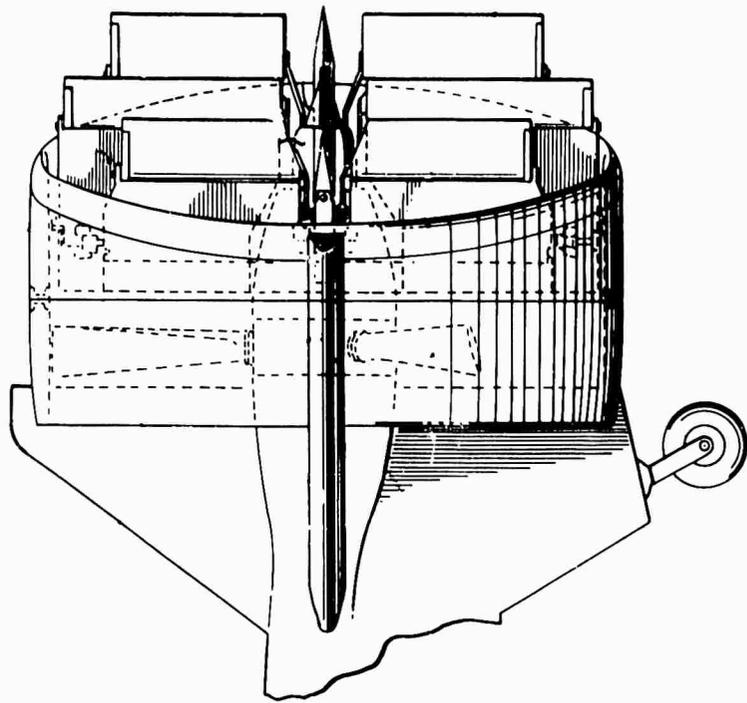
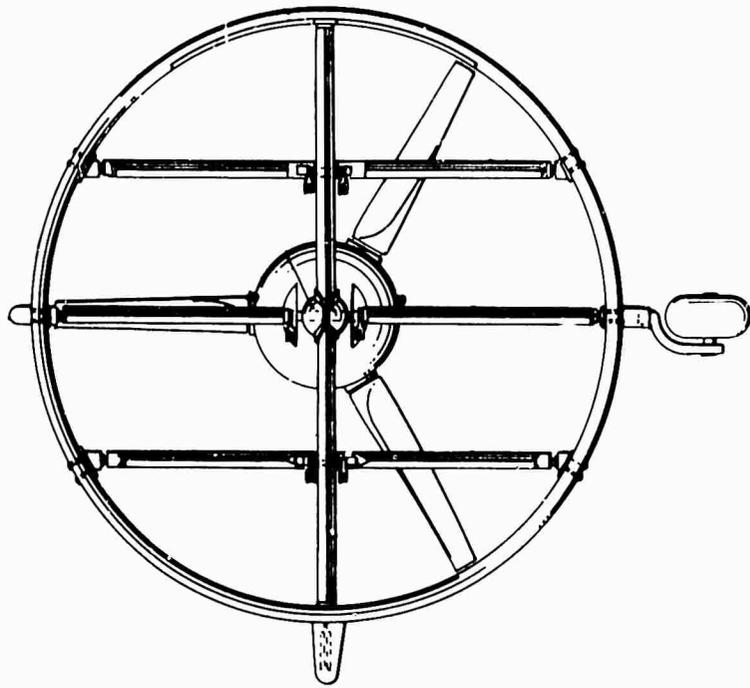


Figure 69. Directional Control Assembly, Pat. No. 3,260,482.

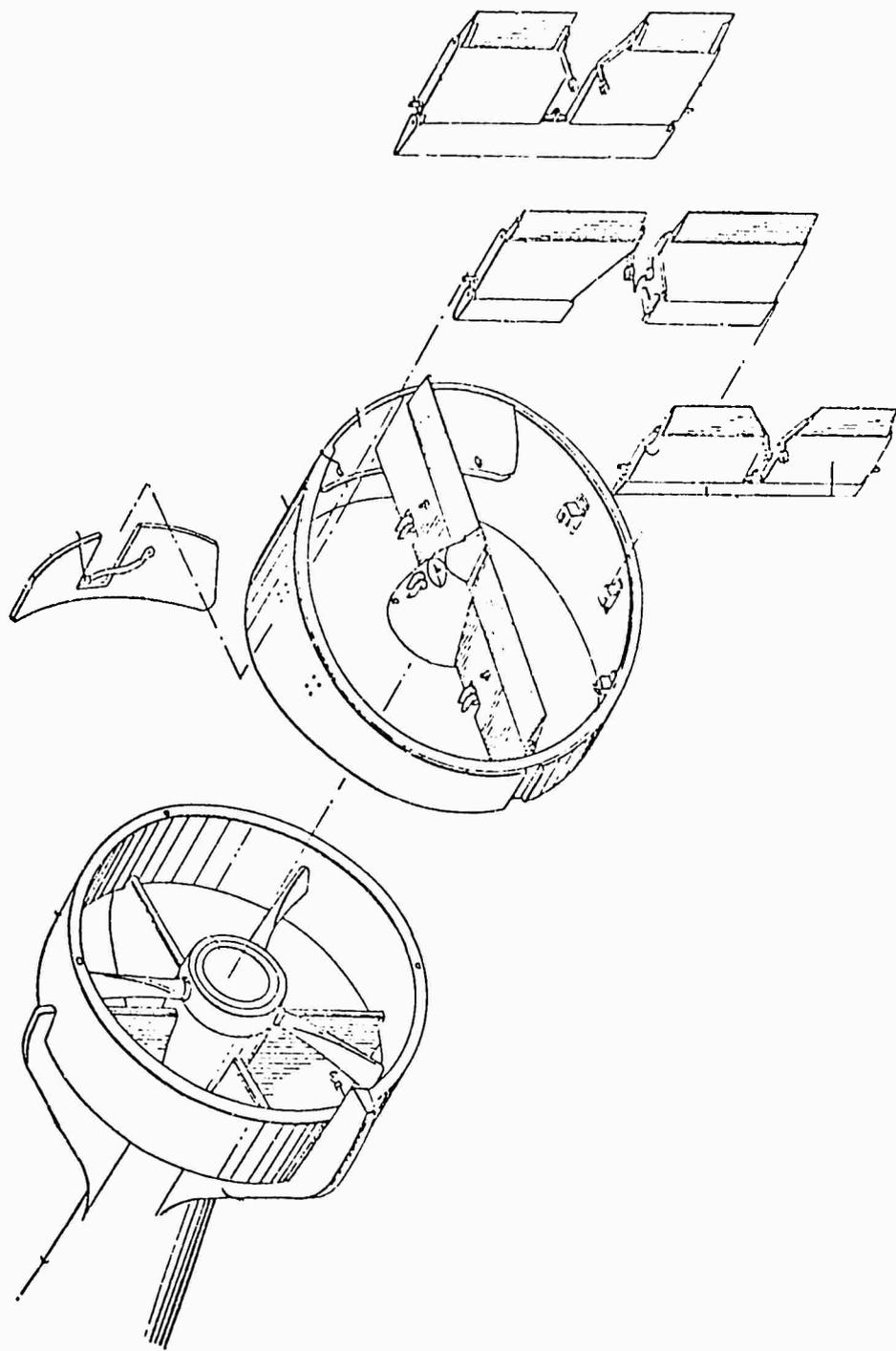


Figure 69. Continued.

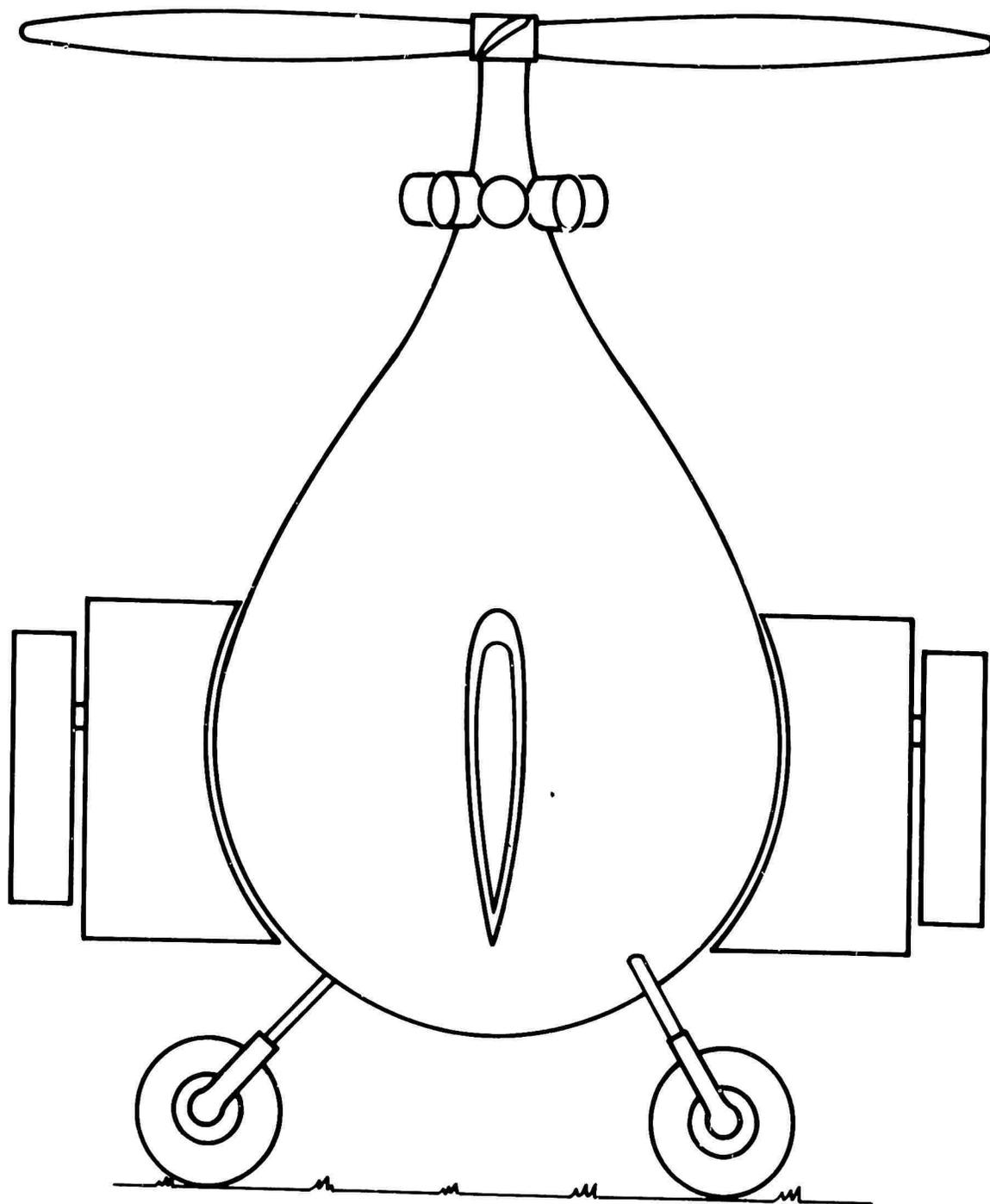


Figure 70. Helicopter Steering Surface Control, Pat. No. 2,437,324.

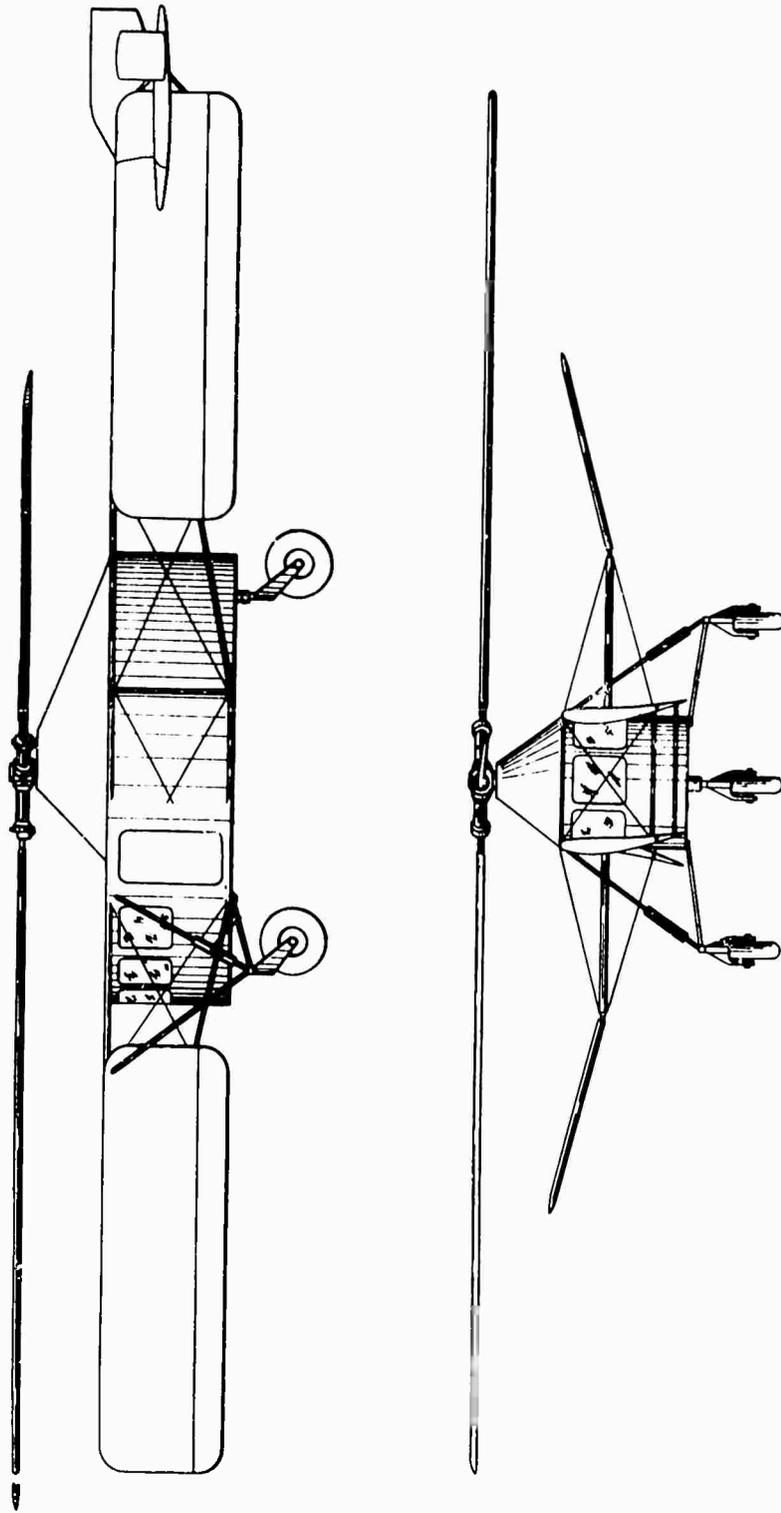


Figure 71. Aircraft, Pat. No. 2,074,805

"Helicopter with Automatic Anti-torque Vane," Reference 4-13

This invention balances the torque of the main rotor by a blowing airscrew with axis substantially parallel with the longitudinal axis of the aircraft and adapted to blow air on to the vertical and horizontal tail airfoils that control the aircraft in pitch and yaw.

According to the invention, the amount of deflection of flaps on the vertical tail necessary for balancing the reaction torque about the vertical axis of the rotor is controlled automatically. Figure 72 illustrates this concept.

"Helicopter Anti-torque Mechanism," Reference 4-14

The purpose of this invention is to counteract the rotor torque of a compound type helicopter by mounting valves/vanes in the wing and aft fuselage directly in the slipstream of the rotor. The vanes are permanently fixed in the interior envelope of the vehicle; the valves can be opened to form an integral inclined surface with the vanes, thus creating a horizontal component force from the slipstream. The valves when closed are flush with the exterior surfaces of the vehicle.

Although this system could be satisfactory in powered hovering flight, it would become ineffective for directional control at low or zero speed autorotation. The concept is shown in Figure 73.

"Aircraft Rotor Drive Means," Reference 4-15

A concentric rotating drum is suggested to force high-pressure air in a manner to drive the main rotor. An adjustable vane in the downwash of the main rotor compensates for rotor torque. The concept shown is oversimplified; it is doubtful that efficiencies attainable would make this scheme attractive. The anti-torque detail is a duplicate of other extending vane concepts which are positioned in the rotor downwash.

The main concept is addressed to total vehicle design. An illustration is shown in Figure 74.

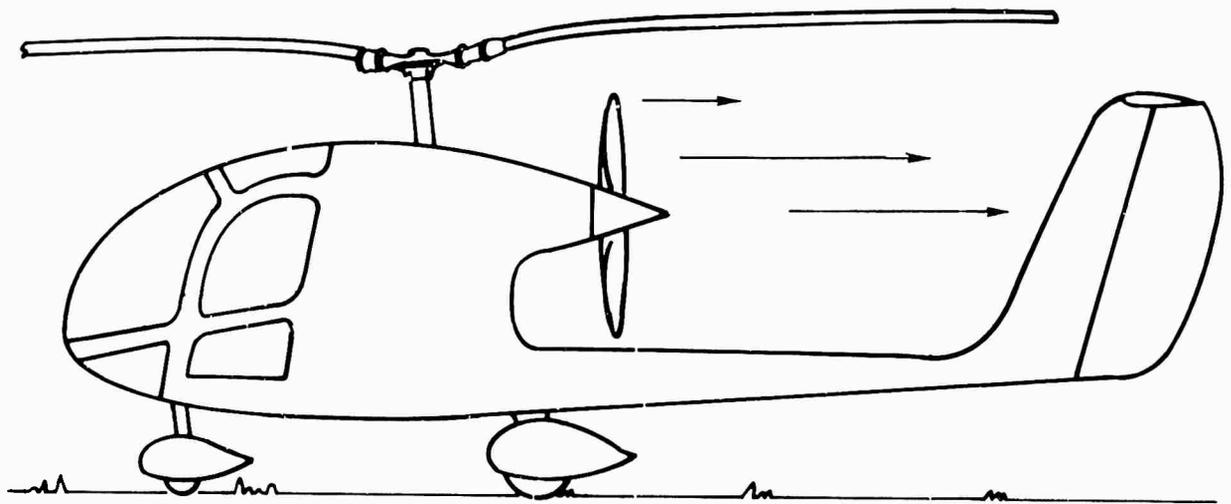


Figure 72. Helicopter With Automatic Anti-torque Vane,
Patent No. 2,547,255.

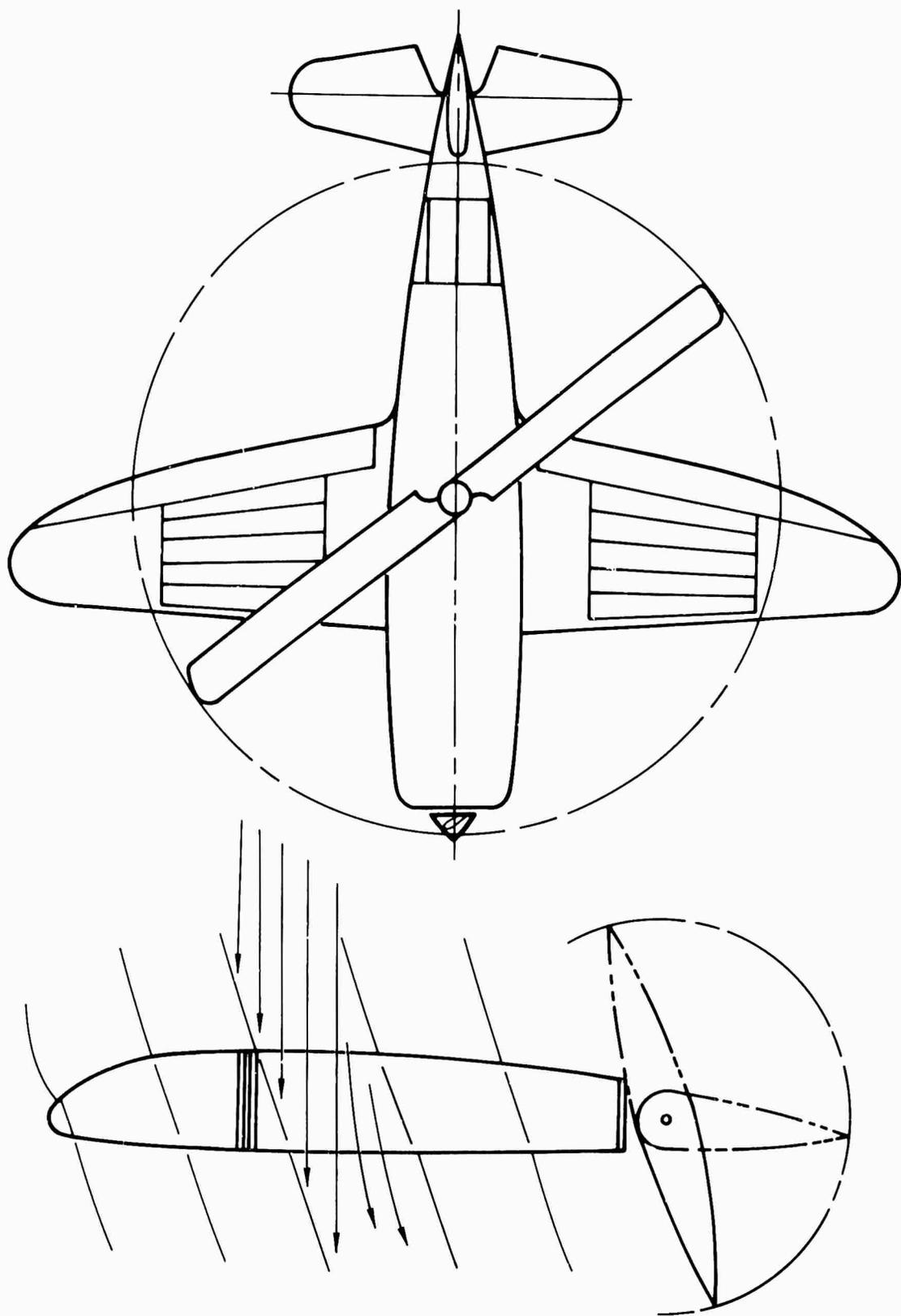


Figure 73. Helicopter Anti-torque Mechanism, Pat. No. 2,575,886.

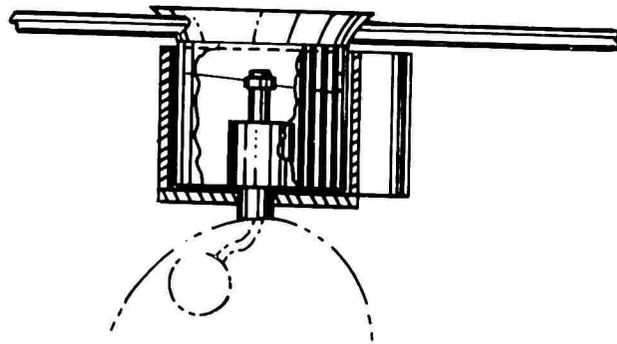
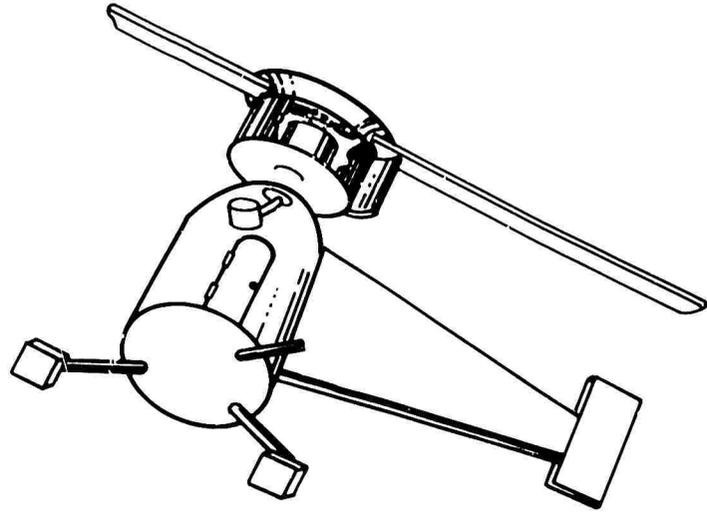


Figure 74. Aircraft Rotor Driving Means, Pat. No. 2,969,937.

5. HORIZONTAL-AXIS ROTARY-WING AIRFOILS

"Lifting Horizontal-Axis Rotating-Wing Aeronautical Systems", Reference 5-1

A comprehensive review of lifting devices in which an airfoil rotates about a horizontal axis (parallel to the spanwise direction) was made by the Aerophysics Company for USAAMRDL. This general group included paddle-wheel-type rotors capable of generating a force in a static ambient air, plus devices, such as Flettner rotors, in which a rotating device generates a force by interacting with air moving relative to it. Those of the latter type were classified previously under "Immersed Aerodynamic Surfaces" in the preceding section of this appendix.

"Helicopter with Paddle-Wheel-Type Tail Rotor", Reference 5-2

The "paddle-wheel rotor" consists of a number of airfoils arranged parallel to the rotation axis, and equally spaced therefrom and from one another. These airfoils are pivotally supported in wheel frames mounted on the axle member, and by means of appropriate linkages are compelled to oscillate about the spanwise axis.

This concept produces a thrust at right angles to the rotary axis in a direction depending on the phasing of the oscillations and with a magnitude dependent on the rpm of its main axle. Figure 75 illustrates this concept.

"Flapping Drive Rotor", Reference 5-3

The referenced memo discusses the feasibility of a forced-flapping-feathering-drive rotor as a means of obtaining a torque-free rotor. A mathematical analysis is presented considering three different blade forms. Expressions for total power requirements in the hovering condition are also derived.

The advantage of the flapping drive is the elimination of an anti-torque device, resulting in:

1. A compact helicopter design .
2. Low drag at high speed.

The disadvantages are:

1. Heavier rotor blades capable of withstanding the high bending stresses.

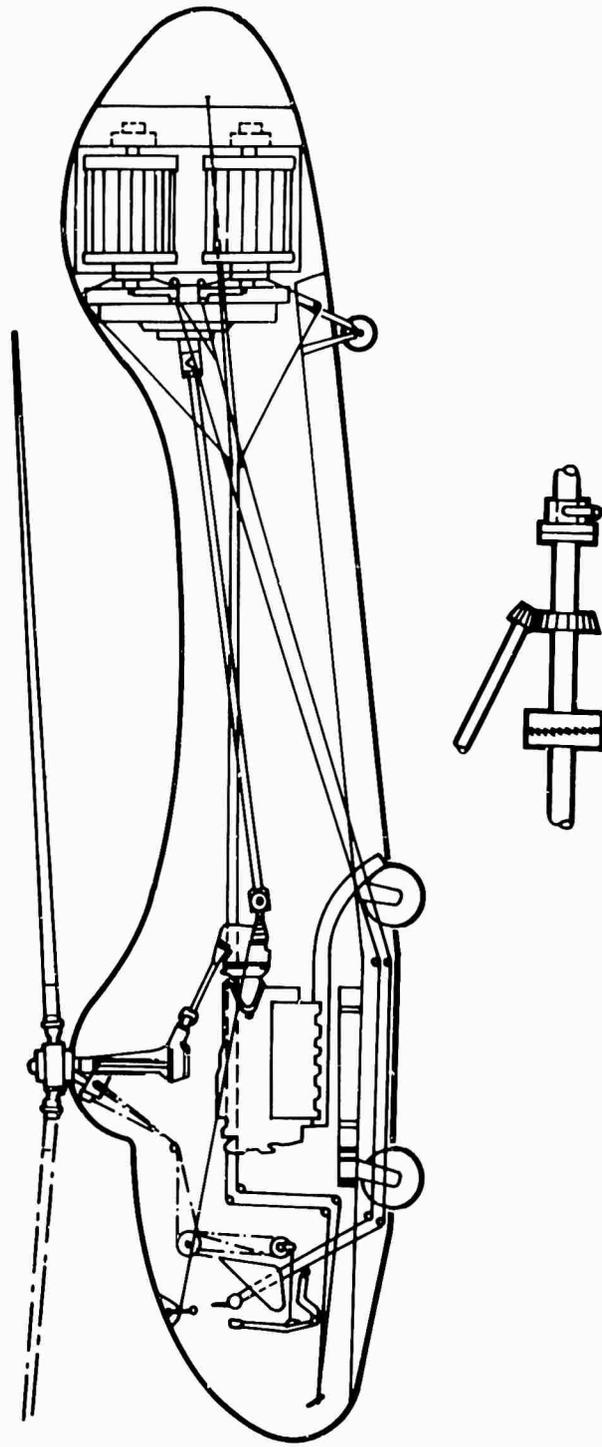


Figure 75. Helicopter With Paddle-Wheel-Type Tail Rotor,
Pat. No. 2,788,075.

2. Additional losses because of the mechanical transmission of the flapping power from the engine to the blade.

This concept is not strictly within the scope of this study. It is listed for completeness, its interesting characteristics, and the essential rotating motions of the blades about the spanwise axis.

6. FUTURE CONCEPTS

"Electromagnetic Rotation", Reference 6-1

This scheme is unusual in that a pure moment is generated without requiring a mechanical reaction. This is accomplished by the interaction of a radial electric current and an axial electromagnetic field. The field is generated by a coil coaxial with a central electrode. The concept is shown in Figure 76, and analyzed in Reference 6-1. The radial current flows through an electrolyte between a central electrode and a conducting cylindrical container. Radial baffles are integrally connected to the container to transmit the anti-torque moment. Use of materials with superconductive properties at room temperature could make this concept quite attractive. Figure 77 illustrates the inapplicability of Newton's third law to moving charges, as discussed in Reference 6-2. Illustrating the order of magnitude of pressures and forces obtainable through electromagnetic technology are the design pressures of 250 psi or 36,000 pounds per square foot obtainable in electromagnetic pumps under development for use with liquid metals in space and nuclear power plants, as reported in Reference 6-3.

"Acoustic Radiation Pressure", Reference 6-4

Reflection of an acoustic sinusoidal \pm pressure variation from a solid reflector produces a steady positive force (radiation pressure) on the reflector, as shown in Figure 78. Very high pressures could be obtained by the use of a resonant closed-loop system employing a liquid/air interface as one of the reflecting surfaces. A conceptual schematic of this system is shown in Figure 79.

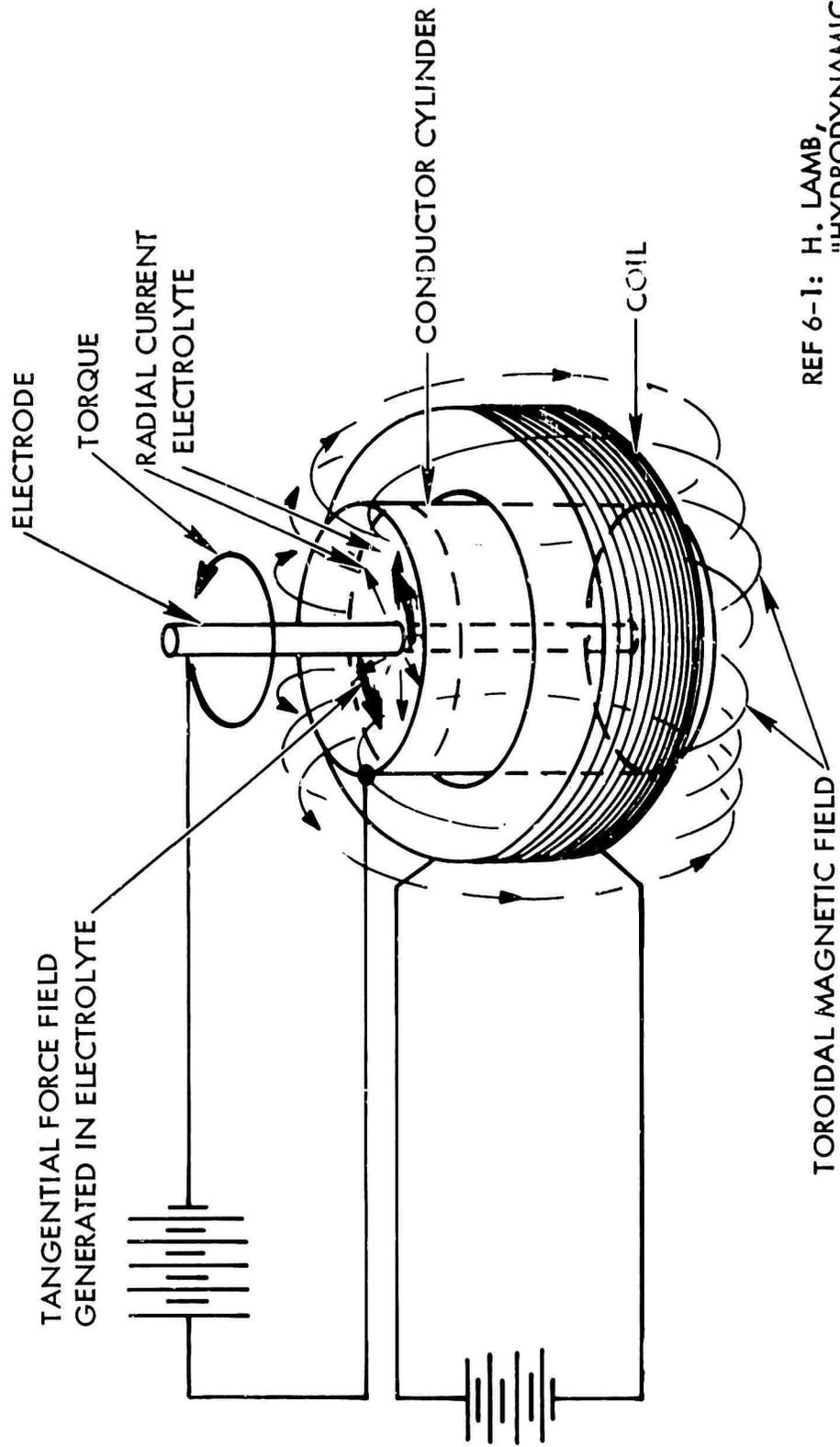
"Controlled Three-Dimensional Vortex", Reference 6-5

This system utilizes a controlled vortex to induce a low-pressure area on one side of the vertical fin. The axis of the vortex is perpendicular to the fin surface and is generated by peripheral jets.

The principle is based on meteorological low-pressure phenomena such as those associated with tornadoes. Figure 80 illustrates the phenomenon.

A broad preliminary investigation reported in Reference 6-5 was conducted to determine if it is feasible to create static lift in air with small-scale cyclonic vortex motion. A survey of the literature and a variety of experiments with simple equipment were conducted. On the basis of this work, the following conclusions and results were obtained:

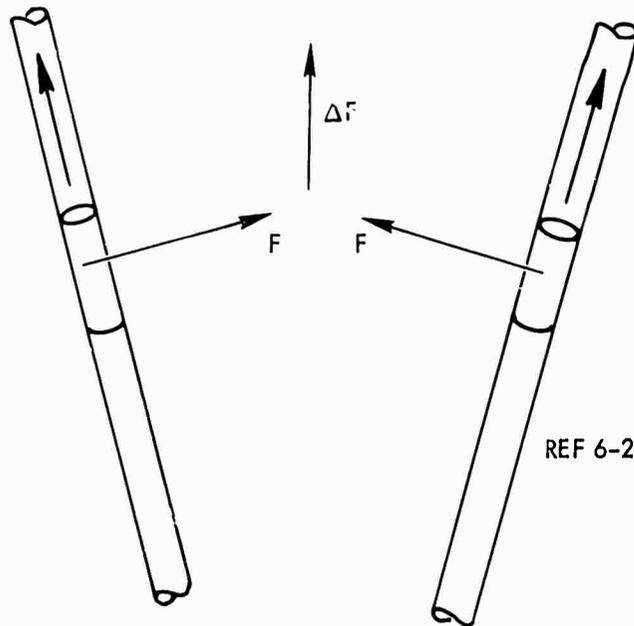
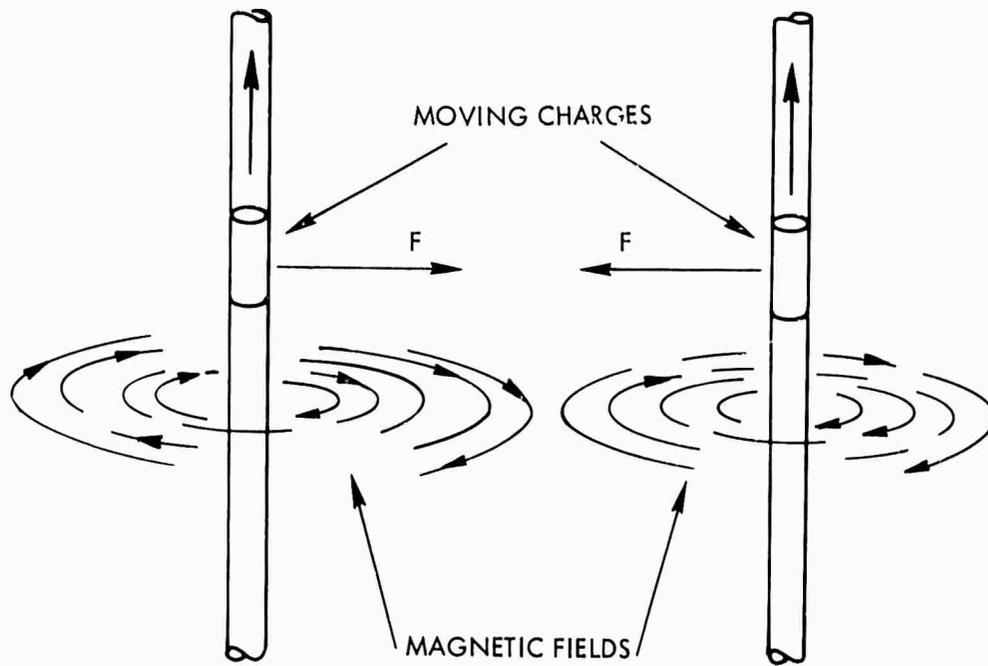
1. Cyclonic vortices were formed between paired suction drains with counterrotating circular flow around them.
2. It should be possible to derive some lift from an arrangement like the preceding one, but magnitudes were not determined.



REF 6-1: H. LAMB, "HYDRODYNAMICS,"
PAGE 27

Figure 76. Electromagnetic Rotation.

ELECTROMAGNETIC INTERACTION FORCES
BETWEEN MOVING CHARGES



REF 6-2: F.W. CONSTANT,
"THEORETICAL PHYSICS,"
PAGE 139

Figure 77. Electromagnetic Interactions Between Moving Charges.

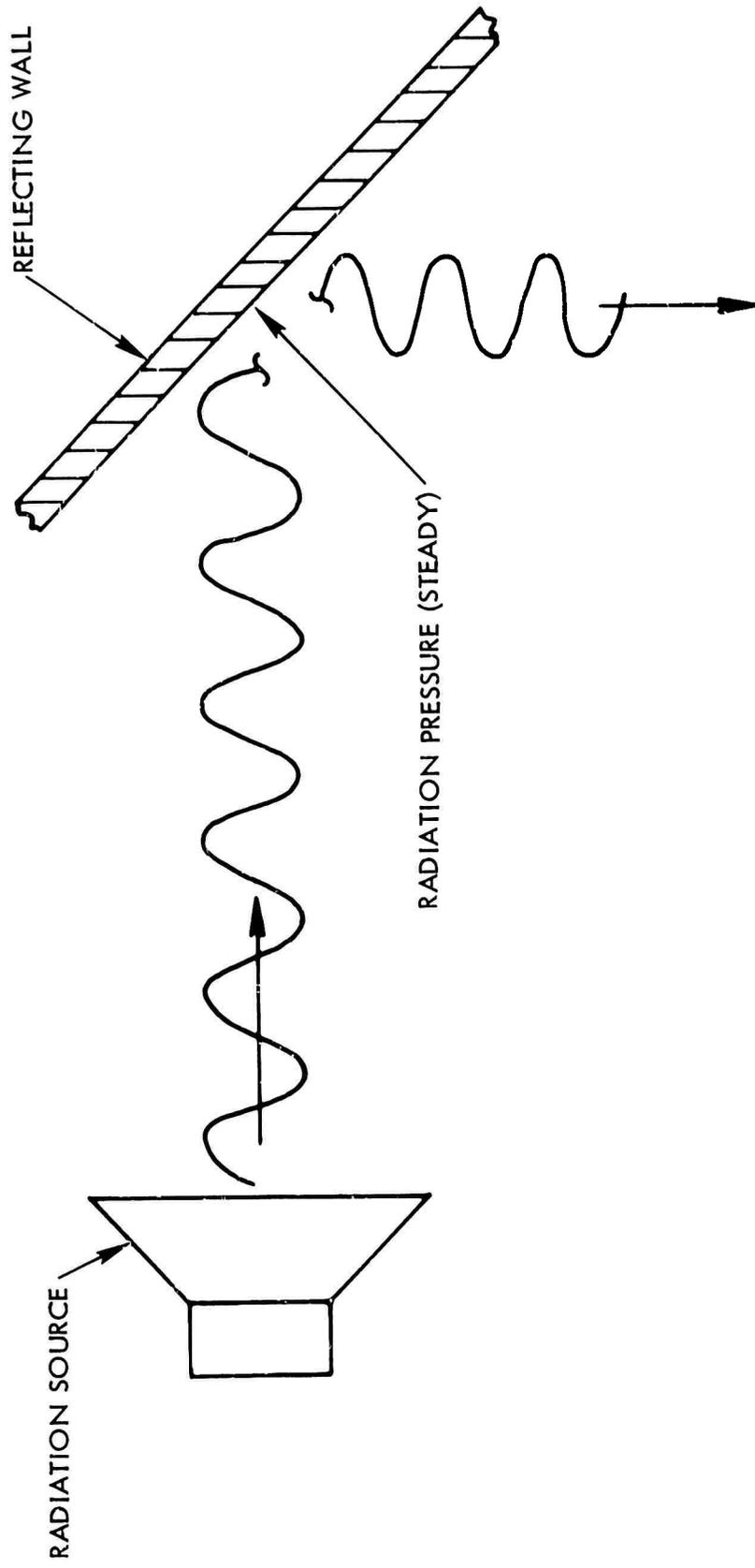


Figure 78. Positive Steady Force from Acoustic Radiation Pressure.

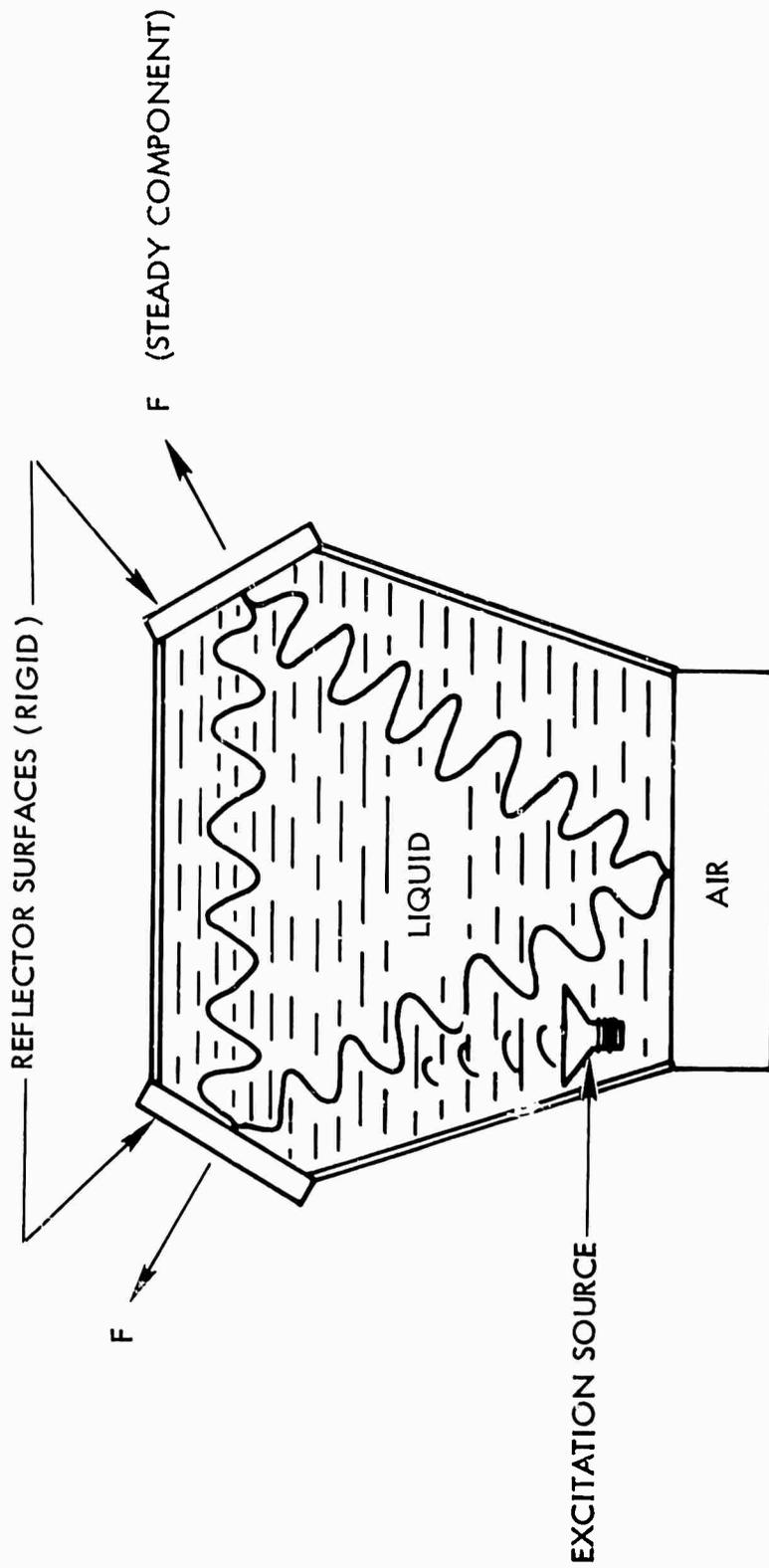
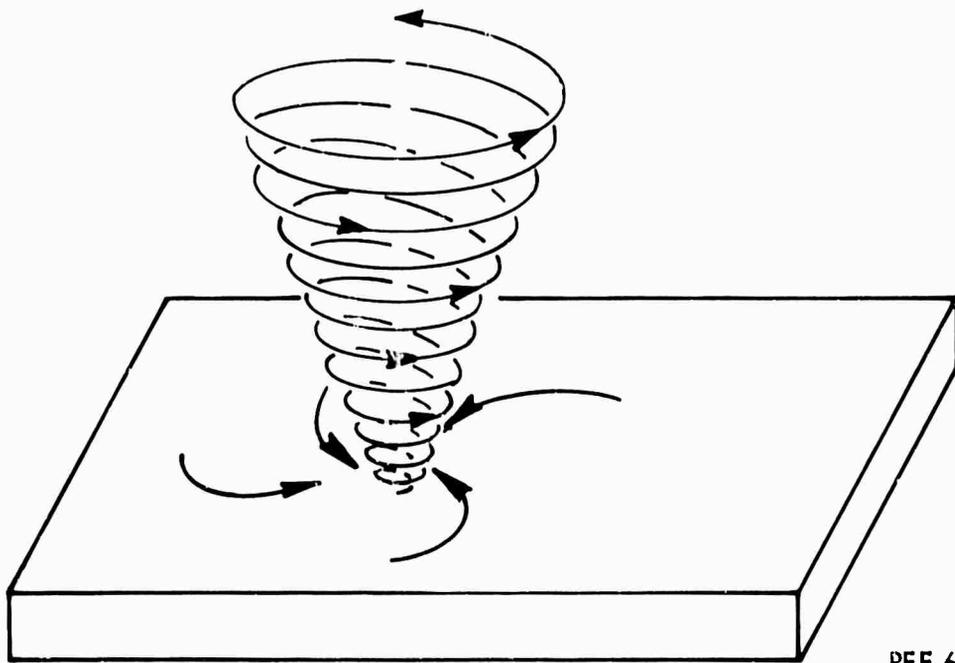


Figure 79. Closed-Loop Radiation Pressure System.



REF 6-5: AFOSR
TR-58-16

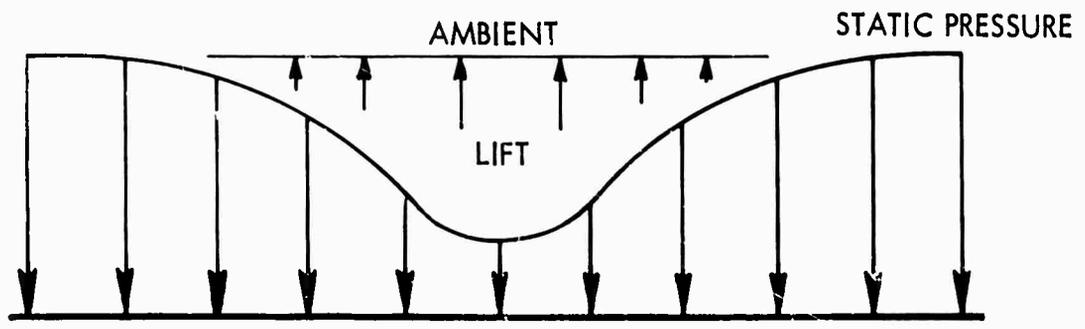


Figure 80. Static Lift by Vortex Motion.

3. It did not appear feasible to induce a cyclonic vortex in air over a single drain which was unenclosed (i.e., completely open to the atmosphere).
4. The possibility that half-ring vortices may be created by means of intermittent jets was explored.
5. The passage of the ends of a half-ring vortex across a surface might induce a pressure differential on that surface.

"Gyroscopic Compound Precession"

Experimental evidence supports the theory that a steady torque about a stationary axis of a gyroscope can be generated by compounding a nose-up pitching velocity with an outward rolling velocity. A multi-gyro package can be constructed utilizing this principle for anti-torque purposes. It would be self-contained, internally mounted and would need no interaction with the surrounding atmosphere. Figure 81 shows a schematic view of this concept. A single gyroscope is shown for clarity. Theory of this concept is related to that of a rising symmetrical top, given in Reference 6-6.

STEADY TORQUE ($T=FR$) ABOUT FIXED AXIS
BY COMPOUND GYRO PRECESSION

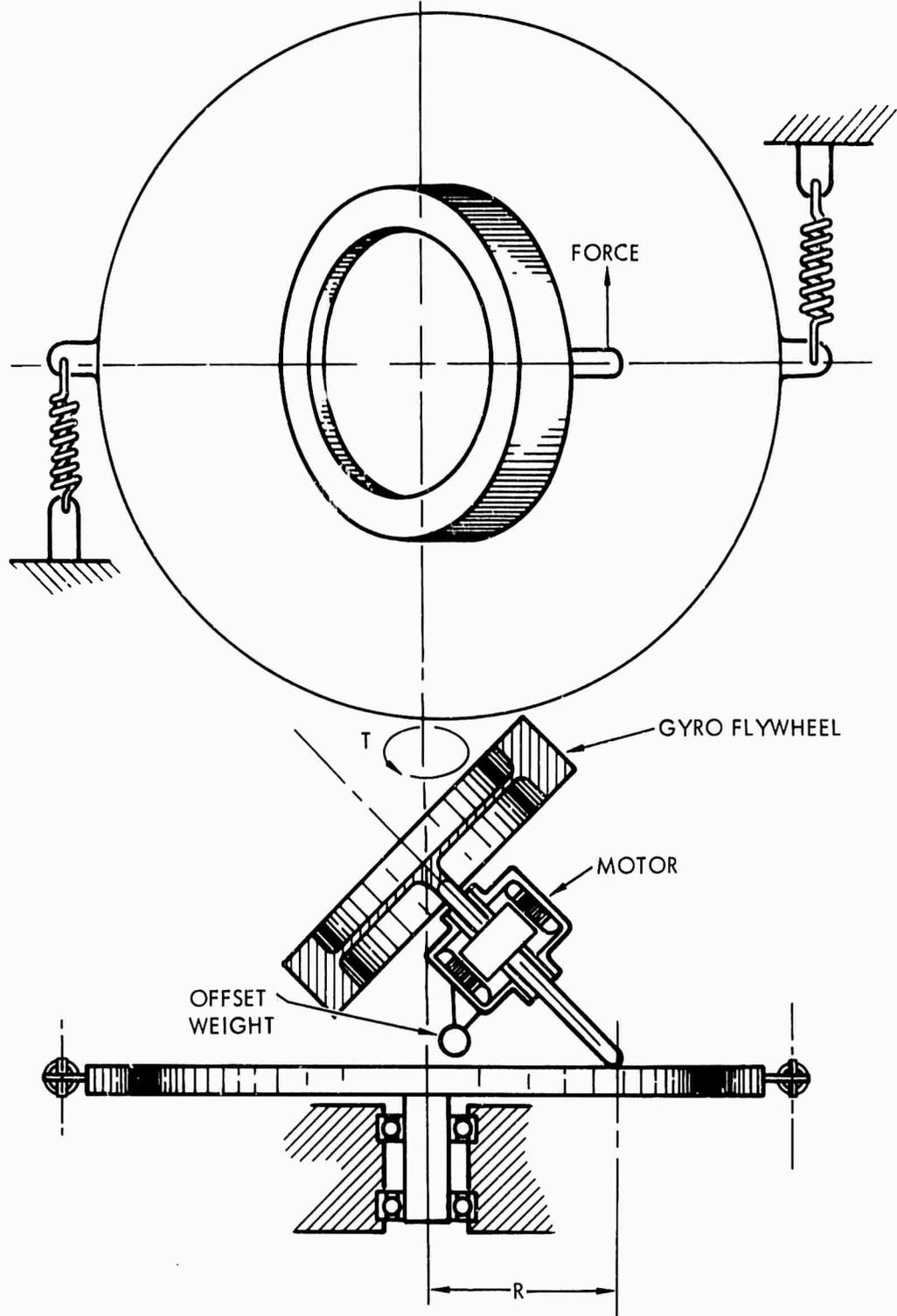


Figure 81. Steady Moment from Gyroscopic Compound Precession.