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AD No. 147928
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VERTOL TRANSPORT AIRCRAFT

Comparative Study

CONFIGURATION STUDIES
VERTOL REPORT NO. R-76

VERTOL

SEP 9 1957

Aircraft Corporation

57AA

42108

formerly - Piasecki Helicopter Corporation

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9-289

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unprepared fields. Once the assumptions of interconnected propellers and non-tilting engines are made, it is relatively easy to provide very effective pitch and yaw control in hovering and low speed flight through the use of submerged fans in the tail interconnected to the propellers. Roll control is obtained through differential thrust of the propeller. This conservative design approach results in an aircraft meeting all safety requirements for control in the event of engine failure at the expense of a more complicated drive system. However, in this arrangement the power plants must be provided with protective armor in the event of turbine failure and must be separately cowled to provide fire protection. Alternate power plant arrangements have been studied for this configuration (slide #5).

In scheme "A", the power plants are alternately staggered to meet all CAA requirements. However, this solution results in a longer power plant package which requires more protection for the cargo compartment area, longer engine drive shafts and long jet pipe extensions.

In scheme "B", the power plants are staggered so that only the turbines would be cleared in the event of failure. This arrangement allows a somewhat shorter overall length and shorter engine drive shafts.

In scheme "C", the power plants are staggered such that a more compact arrangement results with some compromise in CAA requirements. Only the inboard engines require armor for protection. Drive shafts and tail pipe lengths are reduced.

In these alternate arrangements, the basic design criterion of interconnected propellers applies. To obtain a comparison, a non-interconnected propeller version was studied very briefly (slide #6).

In this version of the tilting wing propeller aircraft, two power sections are installed in each propeller nacelle. No interconnects are used so that pitch and yaw control must be obtained from auxiliary power plants located in the tail. The main power plants are tilted with the wings and propellers through approximately 90° for VTO. The hot engine exhaust gases can probably be deflected for operation from unprepared fields. In the event of power plant failure in hovering or low speed flight some electronic means would be required to shut down the opposite engine. Duplication of the system would be required in the event of failure and any malfunctioning of the device would have to be capable of overriding by the pilot. The resulting arrangement although simpler than the interconnected propeller version would require additional development of the main engines and the complication of auxiliary control power plants and their associated installation problems.

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Page No. i
Rept. R-76

**SUMMARY OF FINAL PRESENTATION
OF COMPARATIVE STUDY OF VARIOUS TYPES OF
VTOL TRANSPORT AIRCRAFT**

**Presentation Scheduled by
Air Branch, Office of Naval Research
and held in
Room 2E715A, Pentagon, Washington, D. C.**

May 1, 1956

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INTRODUCTION

In the past several years, the development of low specific weight power plants and of successful methods of generating high lift, has resulted in many proposed design configurations of aircraft capable of vertical take-offs and landings and also capable of much higher flying speeds than contemporary helicopters. In May 1955, Vertol Aircraft Corporation received a contract from ONR, to undertake a broad comparative study of vertical take-off and landing subsonic transport aircraft in order to analyze and categorize these many design concepts. This study has been completed and the results of this analysis are reported in VERTOL Report R-75. = 40-141370

MISSION SPECIFICATIONS

The following mission requirements were set forth (slide #1).

On the map of Europe and Asia, the shaded areas indicate the radius of action capabilities of this assault transport and possible areas of application assuming the operation originates from outside the Soviet Union and its satellites.

Superimposed on the map is a definition of the mission profile. Take-off vertically at sea level with 8000# of payload; climb to 10,000 feet; cruise at 300 mph or greater a total distance of 425 statute miles; the latter 20% being at sea level; land, and return with 4,000 lbs. of payload. The aircraft is capable of hovering at 6,000 ft. and 95°F at any point along the mission. It was also specified that the aircraft shall remain controllable with one engine inoperative and shall be capable of making a "controlled crash" landing.

In addition, the usual assumptions governing fuel consumption calculations were made; engine manufacturer's value of SFC was increased 5%; warm-up @ N.R.P. for 2 minutes and reserve of 10% of initial fuel. It was further assumed that a total hovering duration of five minutes @ military power would be required to effectively perform the basic mission.

PHASE I STUDY

In order to encompass the entire spectrum of VTOL aircraft suitable for transport operation, cruise speed was considered as a variable in the initial study. The results of the Phase I study are presented graphically (slide #2) in terms of take-off gross weight required to meet the mission specifications as a function of cruise speed. It should be realized that this initial study was prepared to determine trends and the approximate competitive position of the various VTOL design concepts. The trends were established through a parametric analysis taking into consideration both the weight and aerodynamic aspects of the problem. Several deviations from the specified mission were made in order to evaluate the numerous VTOL design concepts:

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- a. Payload was assumed to be 8,000 lbs. outbound and inbound.
- b. Cruise at sea level the entire radius of 425 statute miles.
- c. Cruise at 80% of rated military power.

In this phase of the investigation "paper" power plants were employed based on extrapolation of the state of art to 1962.

The VTOL configurations studied may be divided into two categories:

- a. Rotary wing concepts.
- b. Fixed wing concepts.

Under rotary wing concepts the following basic configurations were investigated:

- 1. Conventional helicopter with and without boundary layer control.
- 2. Compound helicopters.
- 3. Retractable plane.

The following configurations were considered under fixed wing concepts:

- 1. Tilt-wing.
- 2. Deflected thrust.
- 3. Vectored lift.
- 4. Vertodyne (Breguet-Kappus).
- 5. Special hovering turbojet.
- 6. Tilting ducted propeller.

In addition to the above configurations, Dr. Lippisch's "Aerodyne" concept for VTOL was also evaluated.

Of the many VTOL transport concepts investigated in the Phase I study, the following six designs appeared to be the most suitable for fulfilling the mission requirements at cruising speeds of 300 mph or greater:

- 1. Tilt-wing propeller.
- 2. Tilting ducted propeller.
- 3. Vectored lift.
- 4. Special hovering turbojet.
- 5. Vertodyne (Breguet-Kappus).
- 6. Aerodyne.

In keeping with the intent of the subject contract, it was decided that once again the broad approach should be taken. Consequently, these six configurations were analyzed to determine the required gross weight to meet the specified mission. The design studies reported herein are preliminary but are indicative of the required size and expected performance of the six selected VTOL configurations.

BASIC DESIGN CONSIDERATIONS

In order to evaluate these six configurations, on a comparative basis, the following basic design considerations were established (slide #3):

a. Dimensional Data

1. Cargo compartment - 8' x 9'-3" x 35' long.* The compartment is large enough to accommodate 35 troops arranged in two rows; one row along each side of the fuselage facing inward. Three standard Army jeeps, four bob-cats jeeps, and numerous other Army vehicles may be loaded internally.
2. The loading ramp angle with respect to the ground line has been kept at 13 degrees (per HAD).
3. The truck bed loading height has been kept at 46 inches.

b. Positive Control in Hovering and Slow Speed Flight

1. Interconnected propellers are provided to insure control during an engine-out condition.
2. Auxiliary devices are provided for positive effective pitch and yaw control.

c. Operation from Unprepared Fields

1. Wherever possible, engines are located so that the hot exhaust gases do not constitute an operational hazard.

d. Engine Availability

1. Only engines which will be available in the period 1956-1960 are considered.

TILT-WING PROPELLER (Slide #4)

The tilt-wing propeller VTOL concept wherein the propellers are used for lift and forward flight thrust is perhaps most applicable in the field of medium speed VTOL aircraft. To meet the mission requirements, the gross weight is 89,841 lbs. and the aircraft is powered with six Allison 550-B1 turboprops. A hovering capability at 6,000 ft. and 95°F is obtained at initial gross weight with water injection.

The design depicted here is the result of a very conservative design approach. The propellers are interconnected and the power plants are mounted so that they remain substantially horizontal. The hot engine exhaust gases do not constitute an operational hazard when taking off from

unprepared fields. Once the assumptions of interconnected propellers and non-tilting engines are made, it is relatively easy to provide very effective pitch and yaw control in hovering and low speed flight through the use of submerged fans in the tail interconnected to the propellers. Roll control is obtained through differential thrust of the propeller. This conservative design approach results in an aircraft meeting all safety requirements for control in the event of engine failure at the expense of a more complicated drive system. However, in this arrangement the power plants must be provided with protective armor in the event of turbine failure and must be separately cowled to provide fire protection. Alternate power plant arrangements have been studied for this configuration (slide #5).

In scheme "A", the power plants are alternately staggered to meet all CAA requirements. However, this solution results in a longer power plant package which requires more protection for the cargo compartment area, longer engine drive shafts and long jet pipe extensions.

In scheme "B", the power plants are staggered so that only the turbines would be cleared in the event of failure. This arrangement allows a somewhat shorter overall length and shorter engine drive shafts.

In scheme "C", the power plants are staggered such that a more compact arrangement results with some compromise in CAA requirements. Only the inboard engines require armor for protection. Drive shafts and tail pipe lengths are reduced.

In these alternate arrangements, the basic design criterion of interconnected propellers applies. To obtain a comparison, a non-interconnected propeller version was studied very briefly (slide #6).

In this version of the tilting wing propeller aircraft, two power sections are installed in each propeller nacelle. No interconnects are used so that pitch and yaw control must be obtained from auxiliary power plants located in the tail. The main power plants are tilted with the wings and propellers through approximately 90° for VTO. The hot engine exhaust gases can probably be deflected for operation from unprepared fields. In the event of power plant failure in hovering or low speed flight some electronic means would be required to shut down the opposite engine. Duplication of the system would be required in the event of failure and any malfunctioning of the device would have to be capable of overriding by the pilot. The resulting arrangement although simpler than the interconnected propeller version would require additional development of the main engines and the complication of auxiliary control power plants and their associated installation problems.

TILTING-DUCTED PROPELLER (Slide #7)

The next slide shows the tilting ducted propeller VTOL aircraft. This concept is very competitive from a gross weight point of view with the tilt wing propeller. Gross weight is approximately 92,000 lbs. and it is also powered with six Allison 550-B1 turboprops. Again it has been assumed that the ducted fans are interconnected. Positive pitch and yaw control is obtained from submerged fans in the tail surfaces in hovering and low speed flight; roll control is obtained through differential propeller thrust. A hovering capability at 6,000 ft. and 95°F is obtained at take-off gross weight with water injection.

VECTORED LIFT (Slide #8)

For true VTOL operation, the vectored lift concept will always be at somewhat of a performance disadvantage due to the losses in thrust that are accompanied with deflecting the slipstream through quite large angles. Consequently, for a given gross weight, the loss in thrust requires a greater power which is reflected mainly in increased power plant weight and its associated components. Gross weight of this concept is approximately 111,000 lbs. It is powered with 8 Allison 550-B1 turboprops. Another disadvantage of this design for VTOL is the awkward position required for take-off resulting in a high nose gear and corresponding increased alighting gear weight. The pitching moments associated with hovering flight are high and have been alleviated somewhat in this design concept by lowering the propellers thrust line, and by use of a controllable forward located stabilizer which is immersed in the propeller slipstream. Additional pitch control is obtained by the tail submerged fan. Yaw control fans are located in the vertical fins. The propellers are all interconnected.

For higher cruise speed potential, the special hovering turbojet, the Vertodyne and the Aerodyne become more promising.

SPECIAL HOVERING TURBOJET (Slide #9)

The concept of obtaining vertical take-off and landing with direct lift turbojets is appealing, since the compromises of the conventional airplane configuration are a minimum. However, it requires a new philosophy of engine installation. For the design concept visualized, 10 clusters of six modified J-85 turbojets would be required for vertical take-off. Each cluster would be designed to operate as an individual engine with a single starting system, fuel system and associated accessories. In addition, three J-85 turbojets are installed in each wing for forward flight propulsion. Two J-85's are located in the tail for pitch and yaw control and may be used for forward propulsion. Roll control is obtained from bleed air of the 3 forward flight engines. Although the concept is interesting for higher cruise speeds there are several disadvantages, other than power plant development, associated with this design for the assault transport mission.

Perhaps the greatest detriment is the hot exhaust gases blasting downward in the take-off and landing flight conditions. Another drawback is the limited time available that can be spent in the VTOL regime of flight due to the high fuel consumption.

VERTODYNE (Slide #10)

The Vertodyne concept appears to be a very promising design for high speed assault transport applications. Ducted fans are located in the inboard section of the wing to provide vertical thrust. The ducted fans are mechanically driven by a power turbine separated by means of ducting from the gas generator of the modified J-79 turbojets. Consequently, in hovering the engines are operated as a turboprop and in forward flight as conventional turbojets. The ducted fans are interconnected. Pitch and yaw control is obtained from the shaft driven tail fans. Control of the aircraft in roll is obtained by differential thrust of the main lifting fans. Acceleration, during transition is achieved by tilting the aircraft forward to obtain a horizontal component of thrust from the ducted fans. Gross weight of this aircraft is approximately 112,000 pounds. It has a maximum speed of 525 mph and cruise speed of 400 mph.

Since the wing area of this design must of necessity be large to accommodate the submerged ducted fans, cruising at still higher altitude would be especially desirable.

AERODYNE (Slide #11)

The Aerodyne concept becomes especially interesting and more competitive from a performance and weight aspect for higher cruising speeds. The gross weight of this aircraft is approximately 121,000 pounds and requires 10 Allison 550-B1 turboprops. Cruising speed is 450 mph and maximum speed is 580 mph. The Aerodyne, however, has two distinct disadvantages for the assault transport mission: first, reliance on power for lift and second, dependence upon electronic devices for stability. Roll and pitch control is achieved through submerged tail fans. Yaw control by flap deflection and differential main propeller thrust. It has a hovering capability of 6,000 ft. and 95°F at take-off gross weight with water injection.

SUMMARY (Slide #12)

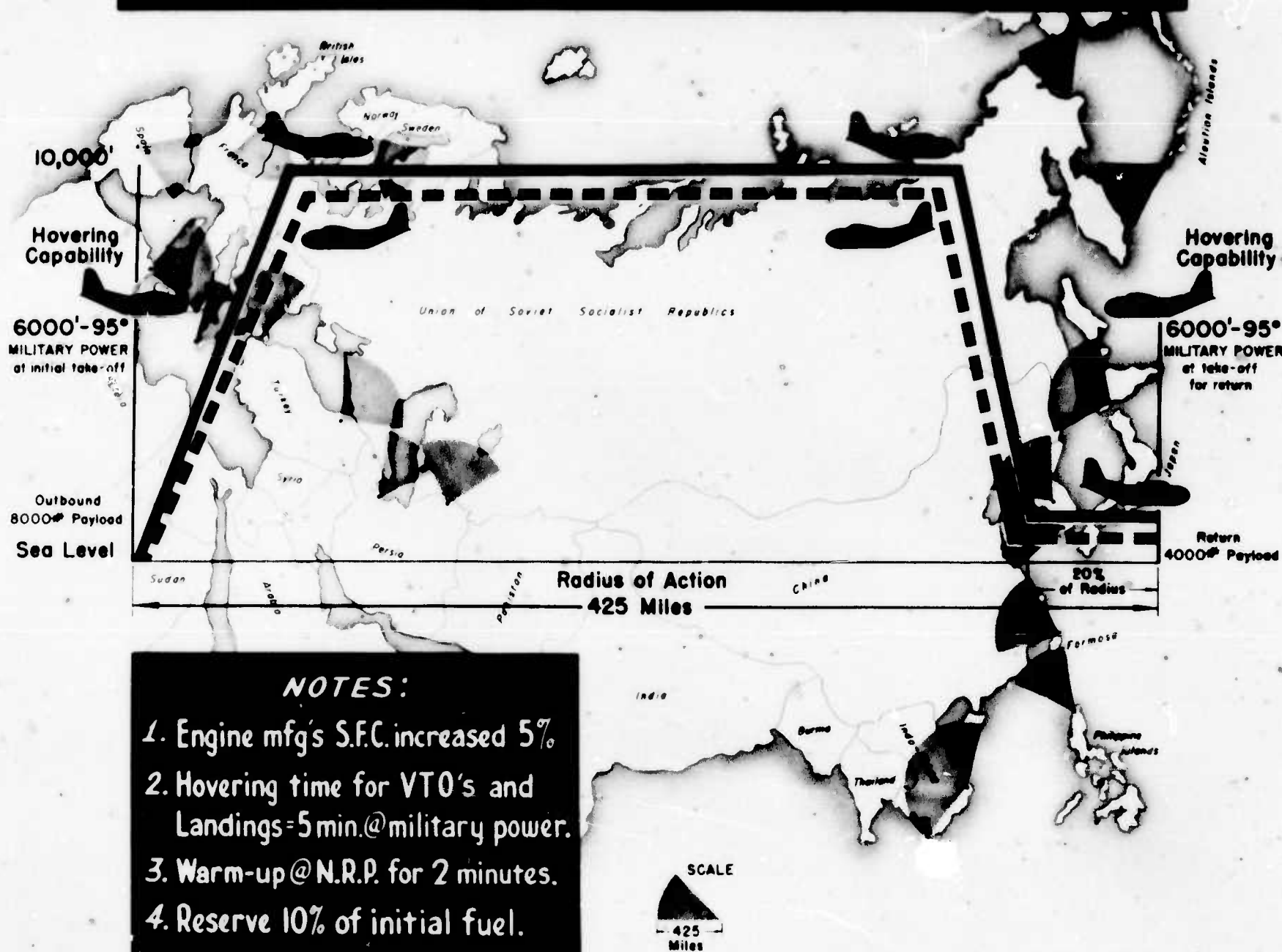
Performance and weight aspects of the six selected VTOL configurations are summarized on the following slide. The spectrum of weights range from the tilt-wing propeller to the Aerodyne. From a weight and performance viewpoint, the tilt-wing propeller and tilting ducted fan are very nearly the same. The vectored lift is substantially heavier and affords some particular problems of control in hovering. The hovering turbojet, Vertodyne and Aerodyne are competitive for VTOL aircraft capable of jet speeds.

In conclusion, it should be emphasized that the comparative study reflects only the weight and performance aspects, and does not reflect design proficiency, or the operational and stability and control problems that may be encountered. Consequently, those concepts that appear to be "optimum" may not prove to be entirely suitable in operation. Some of these problems may be resolved through wind tunnel and component testing. However, the advantages and desirability of having flying test beds to prove and explore the principles of the many competitive VTOL configurations cannot be underestimated.

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VTOL COMPARATIVE STUDY

BASIC MISSION



NOTES:

1. Engine mfg's S.F.C. increased 5%.
2. Hovering time for VTO's and Landings=5 min.@military power.
3. Warm-up@N.R.P. for 2 minutes.
4. Reserve 10% of initial fuel.

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VERTOL

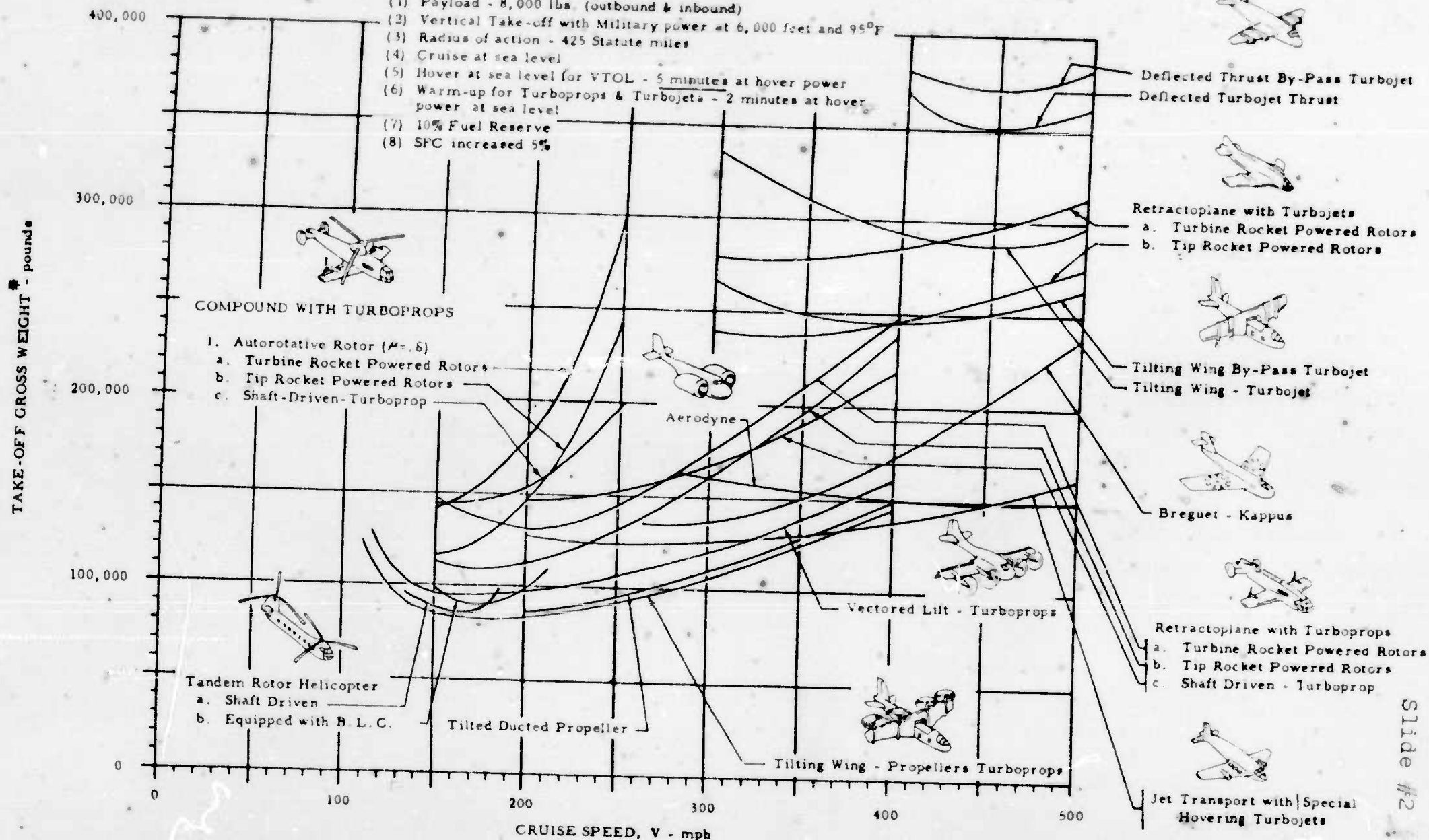
Aircraft Corporation

COMPARATIVE STUDY OF VARIOUS TYPES OF VTOL AIRCRAFT

TAKE-OFF GROSS WEIGHT • VS CRUISE SPEED

DESIGN REQUIREMENTS

- (1) Payload - 8,000 lbs. (outbound & inbound)
- (2) Vertical Take-off with Military power at 6,000 feet and 95°F
- (3) Radius of action - 425 Statute miles
- (4) Cruise at sea level
- (5) Hover at sea level for VTOL - 5 minutes at hover power
- (6) Warm-up for Turboprops & Turbojets - 2 minutes at hover power at sea level
- (7) 10% Fuel Reserve
- (8) SFC increased 5%



*Values shown represent trends only and are not necessarily the absolute minimum take-off gross weights for the specified mission.

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Slide #2

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VTOL COMPARATIVE STUDY

BASIC DESIGN CONSIDERATIONS



POSITIVE CONTROL IN HOVERING AND SLOW SPEED FLIGHT.

1. INTERCONNECTED PROPELLERS TO INSURE CONTROL DURING ENGINE-OUT CONDITION.
2. AUXILIARY DEVICES FOR POSITIVE PITCH AND YAW CONTROL.

OPERATION FROM UNPREPARED FIELDS
1. WHEREVER POSSIBLE, ENGINES ARE LOCATED SO THAT EXHAUST GASES DO NOT CONSTITUTE AN OPERATIONAL HAZARD

ENGINE AVAILABILITY

1. ONLY ENGINES WHICH WILL BE AVAILABLE IN THE PERIOD 1956-1960 ARE CONSIDERED.

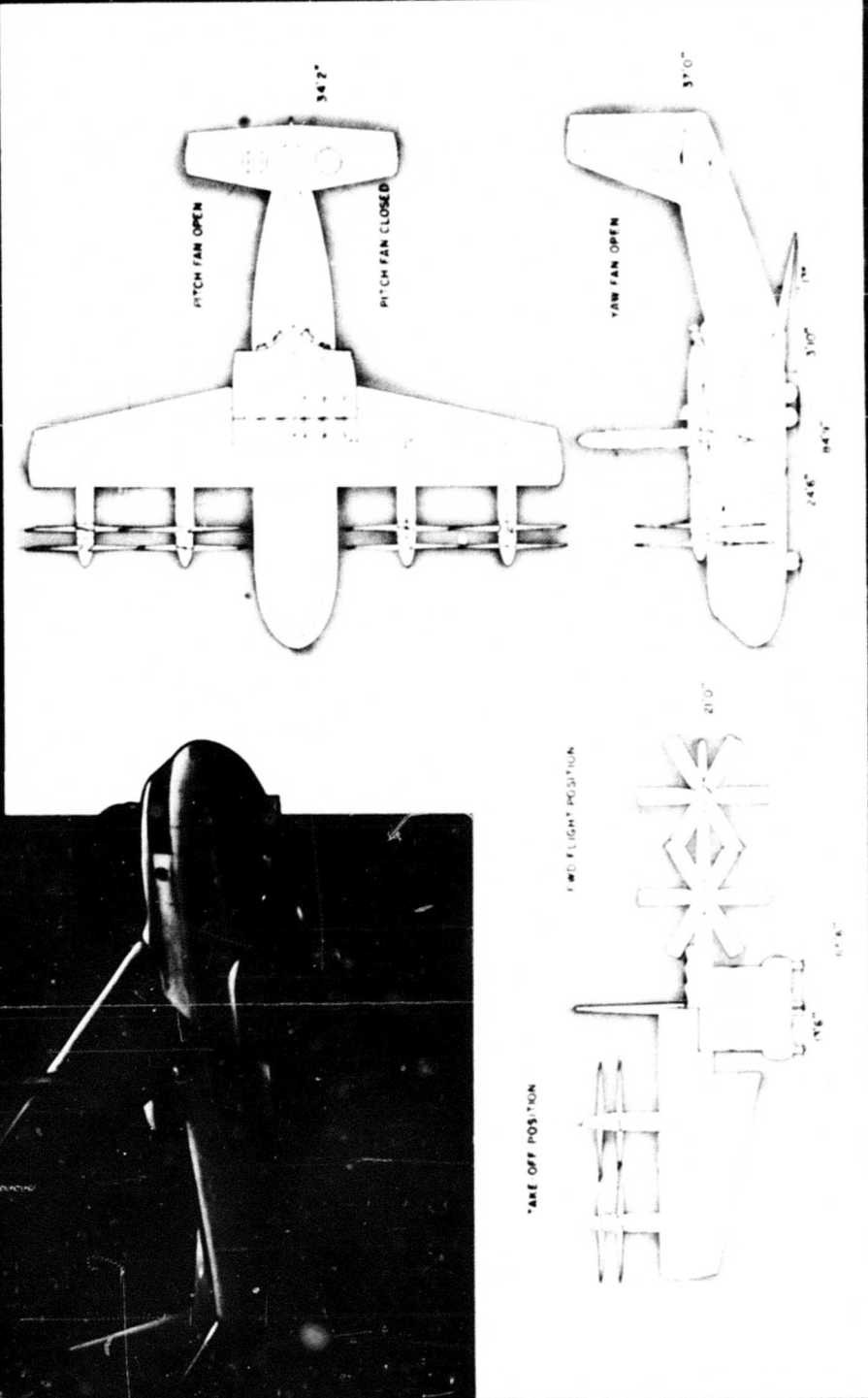
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TILTING WING PROPELLER



GROSS WT.	POWER PLANT	V _{MAX}	V _{CRUISE}
89,841 LBS.	6 ALLISON 550-81 TURBOPROPS	440 MPH AT 10,000 FT.	300 MPH AT 10,000 FT. 3 ENGINES



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Alternate Power Plant Arrangements For Tilting Wing Propeller Aircraft

A



a. POWER PLANTS STAGGERED
TO MEET ALL CAA REQUIREMENTS

B



b. POWER PLANTS STAGGERED
TO CLEAR TURBINES

C

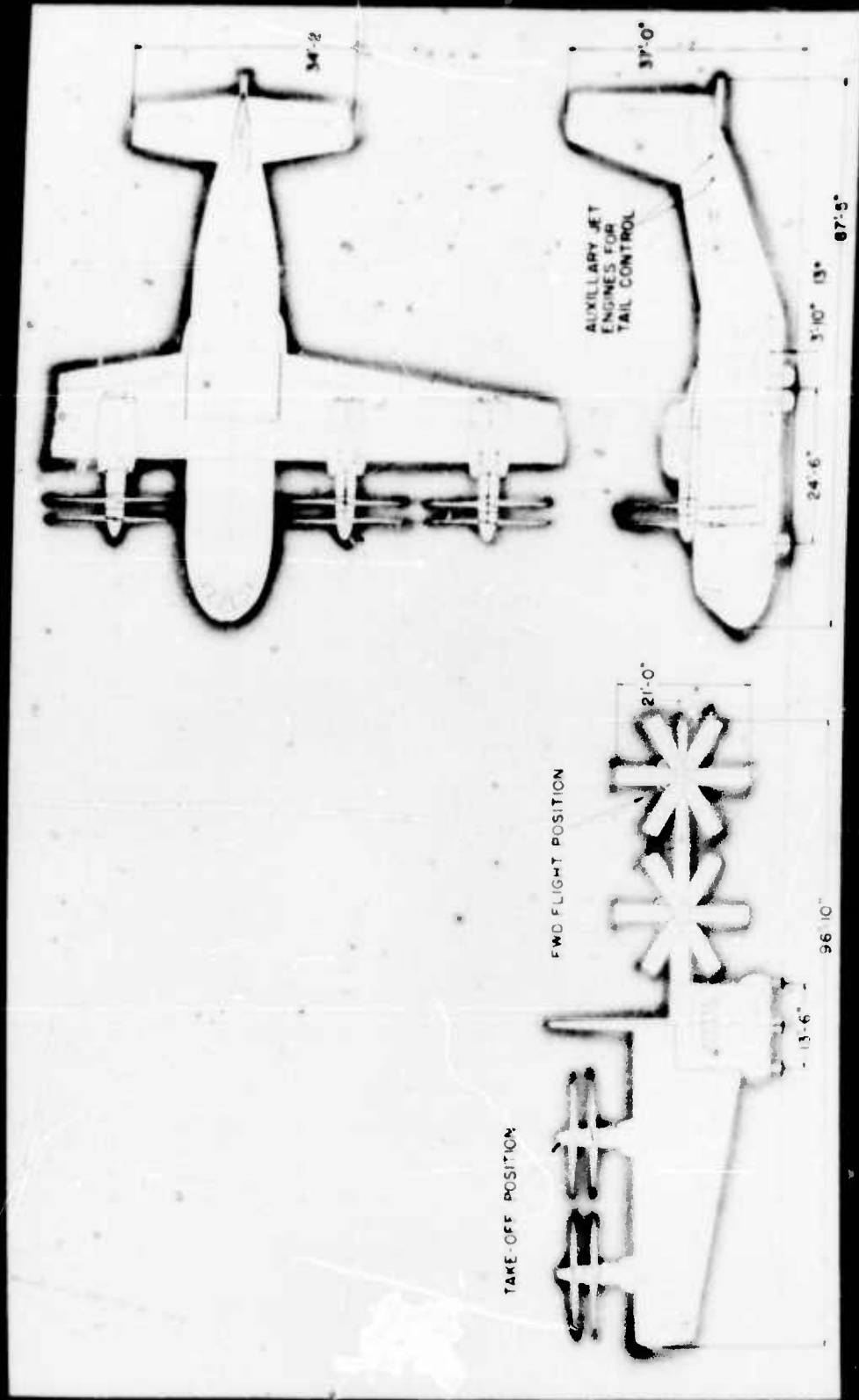


c. POWER PLANTS STAGGERED.
CAA REQUIREMENTS COMPROMISED
FOR COMPACTNESS

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TILTING WING PROPELLER PROPELLERS NOT INTERCONNECTED



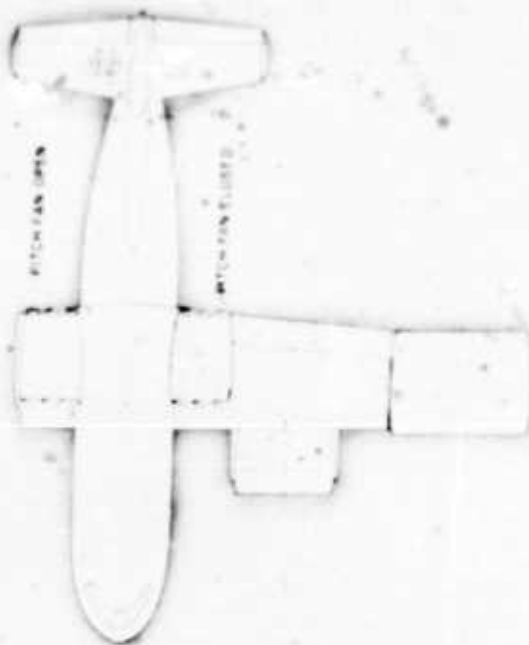
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TILTING DUCTED PROPELLER



GROSS WT.	POWER PLANT	V _{MAX}	V _{CRUISE}
92,228 LBS.	6 ALLISON 550-B1 TURBO PROPS	425 MPH AT 10,000 FT	300 MPH AT 10,000 FT 3 ENGINES



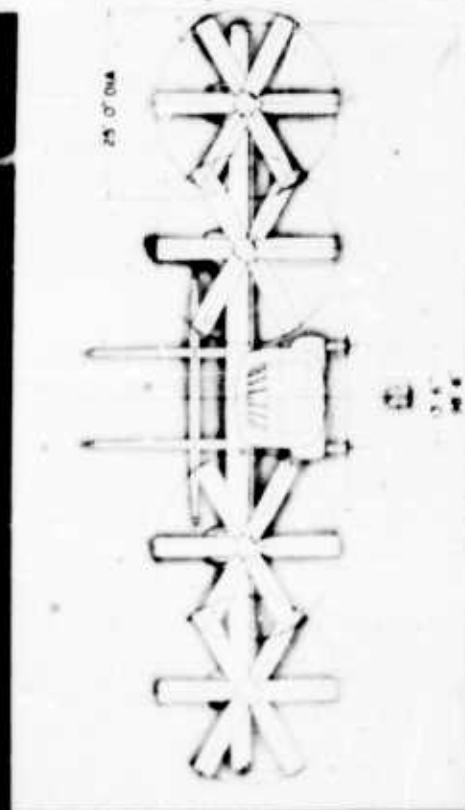
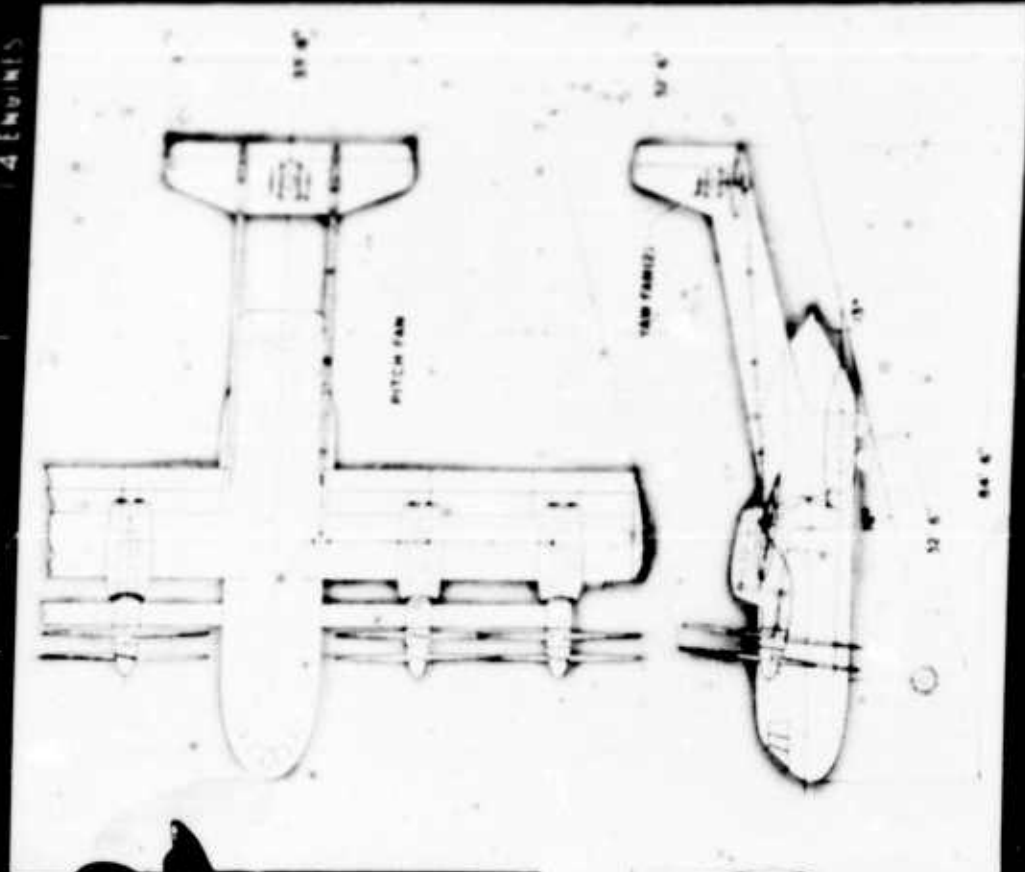
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VECTORED LIFT



GROSS WT.	POWER PLANT	V _{MAX}	V _{CRUISE}
111,343 LBS	8 ALLISON 550-B1 TURBOPROPS	425 MPH AT 10,000 FT	300 MPH AT 10,000 FT
			4 ENGINES

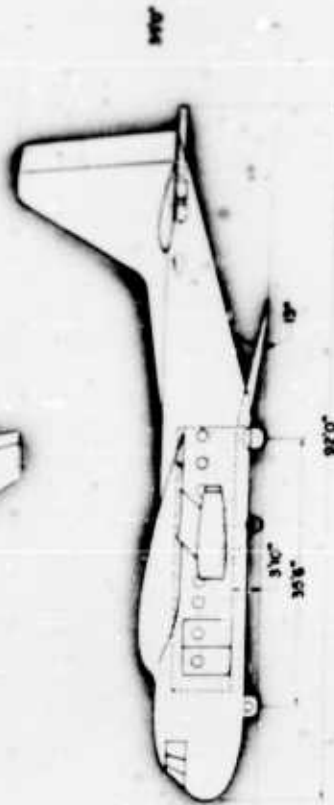
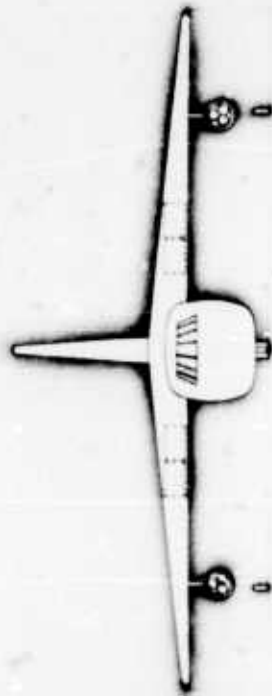
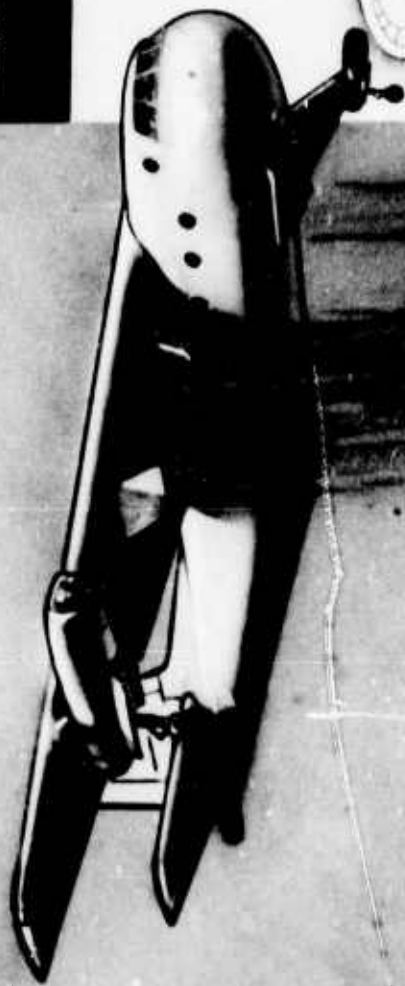


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CONCEPT HOVERING TURBOJET

GROSS WT.	POWER PLANT	V _{MAX}	V _{CRUISE}
109,088 LBS.	68 GENERAL ELECTRIC J-85 TURBOJETS	350 MPH AT 10,000 FT	300 MPH AT 10,000 FT 8 ENGINES

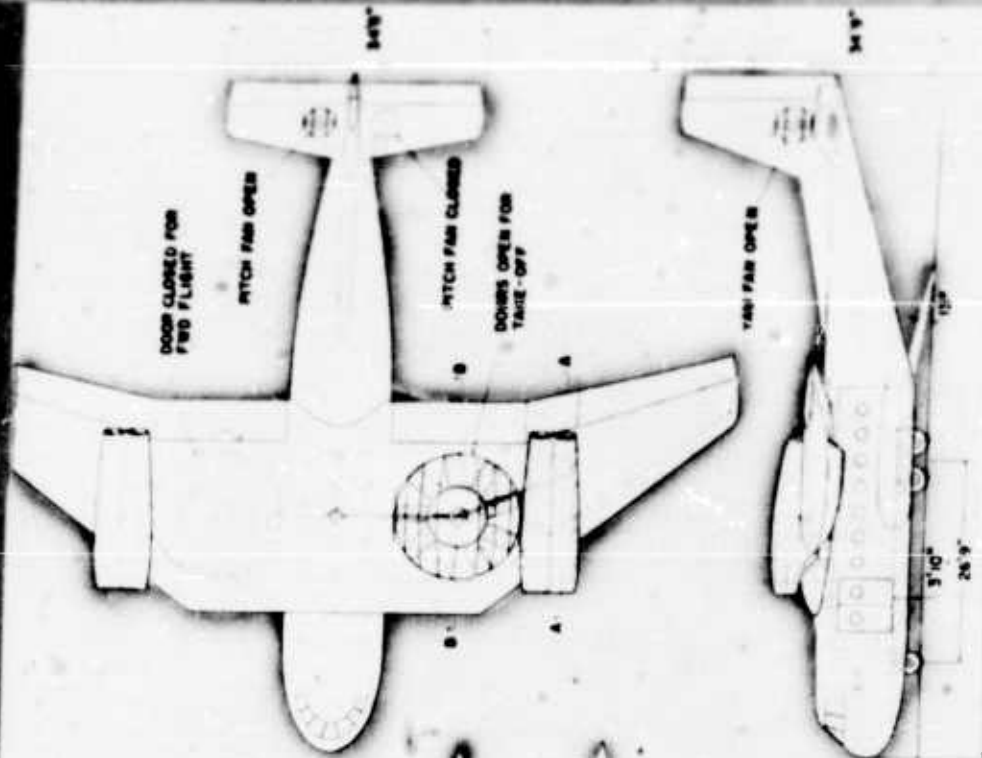
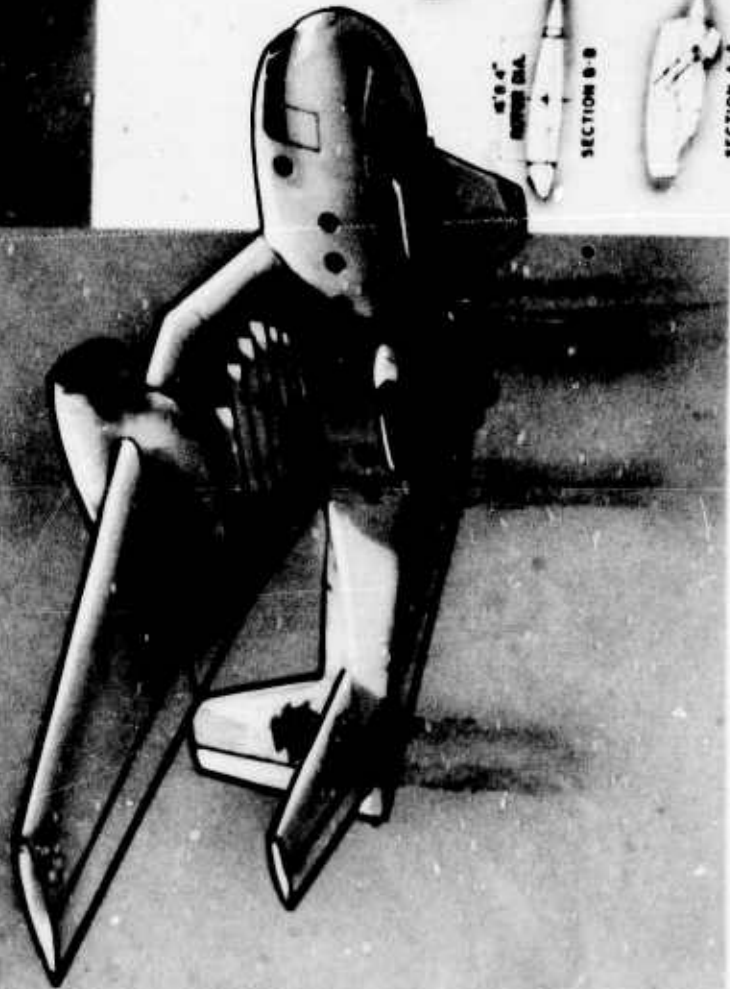


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VIRTODYNE

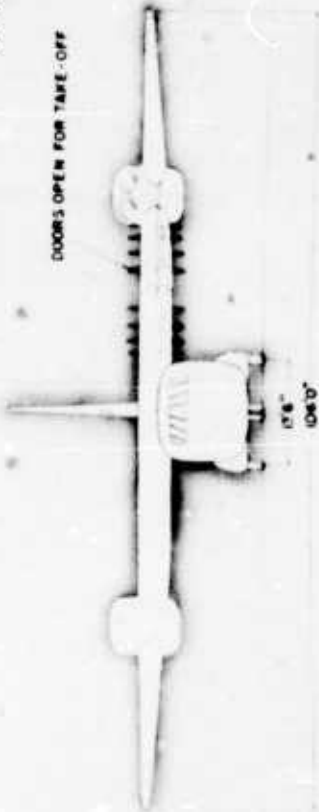
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SECTION B-B



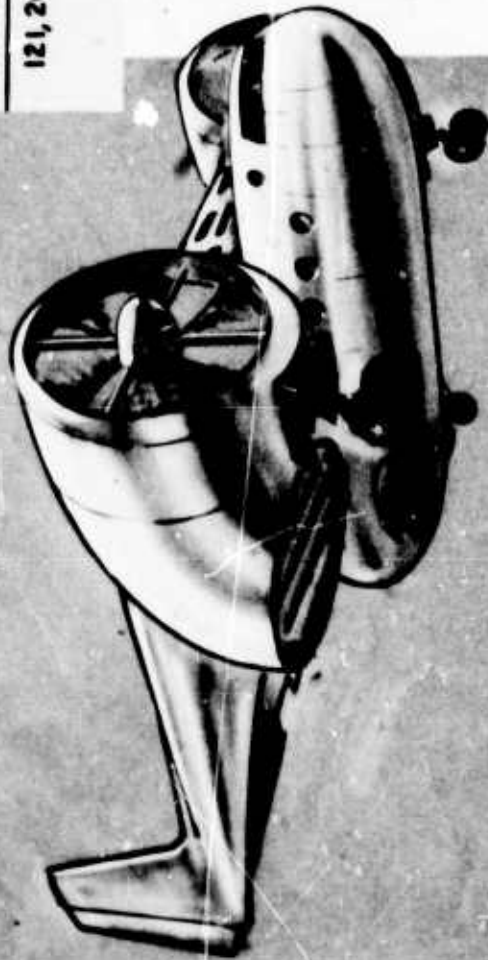
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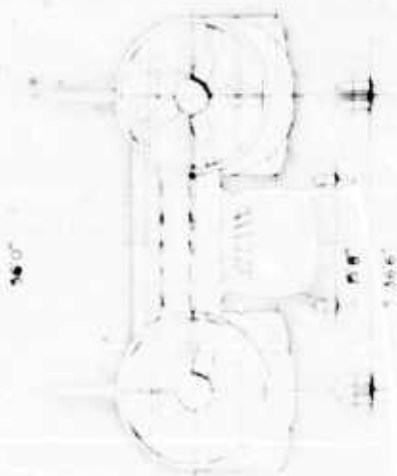
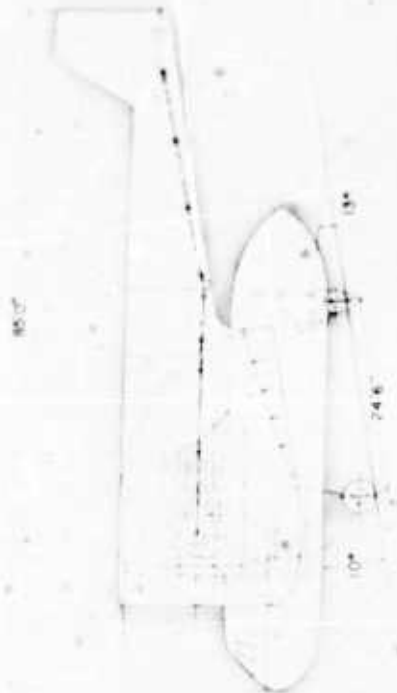
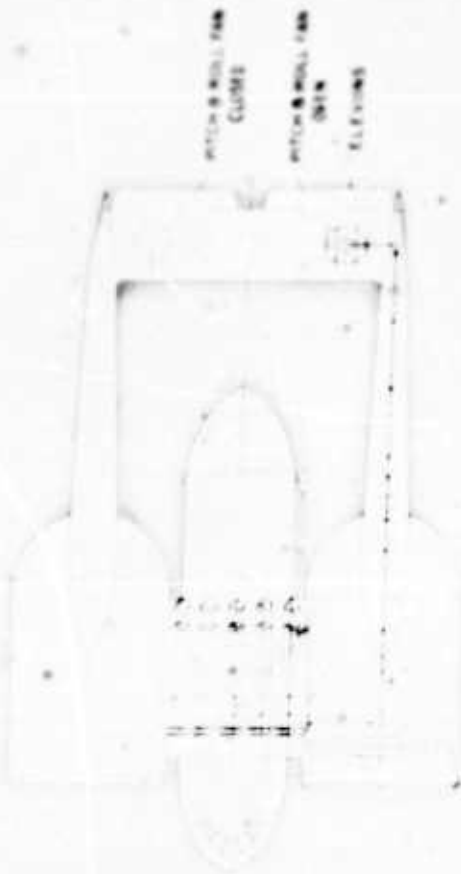
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AERODYNE



GROSS WT.	POWER PLANT	V MAX	V CRUISE
121,265 LBS.	10 ALLISON 550-B1 TURBOPROPS	580 MPH. AT 10,000 FT.	480 MPH. 8 ENGINES AT 10,000 FT.



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VTOL COMPARATIVE STUDY SUMMARY

CODE	WEIGHT EMPTY		USEFUL LOAD
	WEIGHT	VMAX. AT 10,000 FT	VCRUISE AT 10,000 FT
 TILTING-WING PROPELLER	59,159 LBS	440 MPH	300 MPH
	30,682 LBS		89,841 LBS
 TILTING-DUCTED PROPELLER	60,638 LBS	425 MPH	300 MPH
	31,590 LBS		92,228 LBS
 VECTORED LIFT	75,763 LBS	425 MPH	300 MPH
	35,580 LBS		111,343 LBS
 SPECIAL HOVERING TURBOJET	50,458 LBS	350 MPH	300 MPH
	58,630 LBS		109,088 LBS
 VERTODYNE	65,290 LBS	525 MPH	400 MPH
	47,048 LBS		112,338 LBS
 AERODYNE	76,765 LBS	580 MPH	450 MPH
	44,500 LBS		121,265 LBS

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VERTOL AIRCRAFT CORPORATION

VTOL COMPARATIVE STUDY

SUMMARY OF WEIGHTS AND PERFORMANCE

		TILT-WING PROPELLER	TILTING DUCTED PROPELLERS	VECTORED LIFT	SPECIAL HOVERING TURBOJET	VERTODYNE (BREGUET- KAPPUS)	AERODYNE
	Units						
WEIGHTS:							
GROSS WEIGHT	lbs.	89841	92228	111343	109088	112338	121265
WEIGHT EMPTY	lbs.	59159	60638	75763	50458	65290	76765
PROPELLER	lbs.	8736	11155	11328		4580	4360
WING	lbs.	7275	6940	11650	7060	11500	12450
TAIL	lbs.	2690	2700	3020	3150	3180	3900
BODY	lbs.	6746	7480	7890	8030	8130	9725
ALIGHTING GEAR	lbs.	4040	3600	5350	4200	4360	5040
PROPULSION	lbs.	17827	19760	25977	22728	25130	30640
DRIVE SYSTEM	lbs.	6875	3843	6103		2985	4300
FIXED EQUIPMENT	lbs.	4970	5160	4445	5290	5525	6350
USEFUL LOAD	lbs.	30682	31590	35580	58630	47048	44500
CREW	lbs.	600	600	600	600	600	600
PAYLOAD	lbs.	8000	8000	8000	8000	8000	8000
FUEL	lbs.	(19940)	(20865)	(24450)	(47600)	(37510)	(31810)
HOVERING AND WARM-UP	lbs.	1540	1565	2050	12800	3310	2610
CRUISE	lbs.	18400	19300	22400	34800	34200	29200
ENGINE OIL	lbs.	300	300	400	1360	300	1000
XMSN OIL	lbs.	460	460	300		300	400
TRAPPED LIQUIDS	lbs.	432	390	580	1020	288	1190
WATER (FOR INJECTION)	lbs.	900	925	1200			1540
MISCELLANEOUS	lbs.	50	50	50	50	50	50
POWER PLANT:		Allison 550-B1	Allison 550-B1	Allison 550-B1	General Electric J-85	General Electric J-79	Allison 550-B1
NUMBER		6	6	8	68 (60-hover 8-fwd.)	4	10
TYPE		Turboprop	Turboprop	Turboprop	Turbojet	Turbojet	Turboprop
TAKE-OFF PER ENGINE (DRY)		5168 SHP	5168 SHP	5168 SHP			5168 SHP
MILITARY PER ENGINE (DRY)		5168 SHP	5168 SHP	5168 SHP	2450 lbs.	10000 lbs.	5168 SHP
NORMAL PER ENGINE (DRY)		4590 SHP	4590 SHP	4590 SHP	2000 lbs.	9700 lbs.	4590 SHP
PERFORMANCE:							
MAXIMUM FORWARD SPEED							
S.L. N.R.P.	mph	425	410	400	330	510	600
10000' N.R.P.	mph	440	425	425	350	525	580
CRUISE SPEED							
S.L. N.R.P./ NO. OF ENGINES	mph	300/3	300/3	300/4	300/8	325/4	500/8
10000' N.R.P./ NO. OF ENGINES	mph	300/3	300/3	300/4	300/8	400/4	450/8
HOVERING CEILING @ 95°F	ft.	6000 (1)	6000 (1)	6000 (1)	6000	6000	6000 (1)
RADIUS OF ACTION (2)	mi.	425	425	425	425	425	425

NOTES: (1) WITH WATER INJECTION.

(2) MFG. SFC INCREASED 5% - 2 MIN. WARM-UP @ N.R.P. - 5 MIN. HOVERING @ MILITARY POWER. - 10% RESERVE.

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