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V/STOL TILT-ROTOR STUDY
TASK I

CONCEPTUAL DESIGN
(NASA CONTRACT NAS2-6599)

VOLUME I
REPORT 300-099-005

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I. SUMMARY

A conceptual design study was conducted to define a representative military and/or commercial tilt-proprotor aircraft under Task I of the NASA V/STOL Tilt-Rotor Aircraft Study, Contract NAS2-6599. The resulting aircraft design is designated the Bell D302.

The purpose of this task was to define an operational aircraft which would serve as a reference toward which flight research tasks, and a NASA research aircraft as defined under Task II, could be oriented. The time frame considered was for aircraft that would become operational in 1980-1985 (aircraft development to start in the 1975-1980 time frame). The level of structural technology selected for the operational aircraft was based primarily on aluminum, steel, titanium, and adhesive-bonded structures. Engine selection was from those engines predicted to achieve PFRT status by 1975.

The approach embodied in the conceptual design study drew on Bell Helicopter Company's experience with the tilt-proprotor configuration. This includes analytical, experimental, full-scale wind tunnel and flight-test experience. Specific programs have been the XV-3 aircraft, the Army Composite Aircraft program, and full-scale tests of a 25-foot proprotor (designed for use on the research aircraft) in the NASA-Ames Large-Scale Wind Tunnel.

The Bell D302 is a twin-engine aircraft using advanced turboshaft engines of 6000 shp each. The maximum gross weight for commercial missions is 44,100 pounds and 58,511 pounds for military missions. The proprotors are 48-foot diameter, each with three blades of 30-inch chord.

The D302 can carry 40 passengers in a commercial operation over stage lengths of 400 nautical miles at cruise speeds of 348 knots at a cruise altitude of 30,000 feet on a hot day. In a military mission it can carry 48 troops or five tons of cargo for radii up to 500 nautical miles on a standard day. Maximum speed is 358 knots at 25,000 feet on a standard day and 370 knots on a (MIL-STD-210A) hot day.

The data presented in the following sections further describe the aircraft, its weight, performance, noise, stability and control, dynamic characteristics, its maintainability, reliability, and operating economics. This is concluded with an assessment of the needed research to design with confidence operational aircraft such as the D302.

II. AIRCRAFT DESCRIPTION

The D302 is a low disc-loading, 44,100-pound gross weight, tilt-proprotor VTOL. A general arrangement layout of the D302 is shown in Drawing D302-960-001. Bell Helicopter Company's experience with stiff in-plane rotors on 15,000 helicopters led to the selection of the gimbal-mounted hub. A nonrotating hub spring increases control power in helicopter mode. A proprotor with a disc loading of approximately 12 psf, with three blades and a solidity of 0.10 was selected. The proprotors have been aerodynamically optimized to have good hovering capability and to operate efficiently when they are tilted forward for high-speed airplane mode of flight. The hover tip speed of 800 feet per second was selected as a compromise between low noise and the weight of the proprotors and transmissions. This compares with over 900 feet per second for many propellers and 814 and 746 feet per second on the UH-1D and UH-1B Huey helicopters respectively. The D302 cruise airspeed of 520 feet per second was selected as a compromise between propulsive efficiency and transmission weight which is dependent on design torque. It was found that cruise airspeed need not be reduced below 600 feet per second to achieve a good propulsive efficiency on a MIL-210A hot day because of the higher speed of sound and reduced compressibility losses.

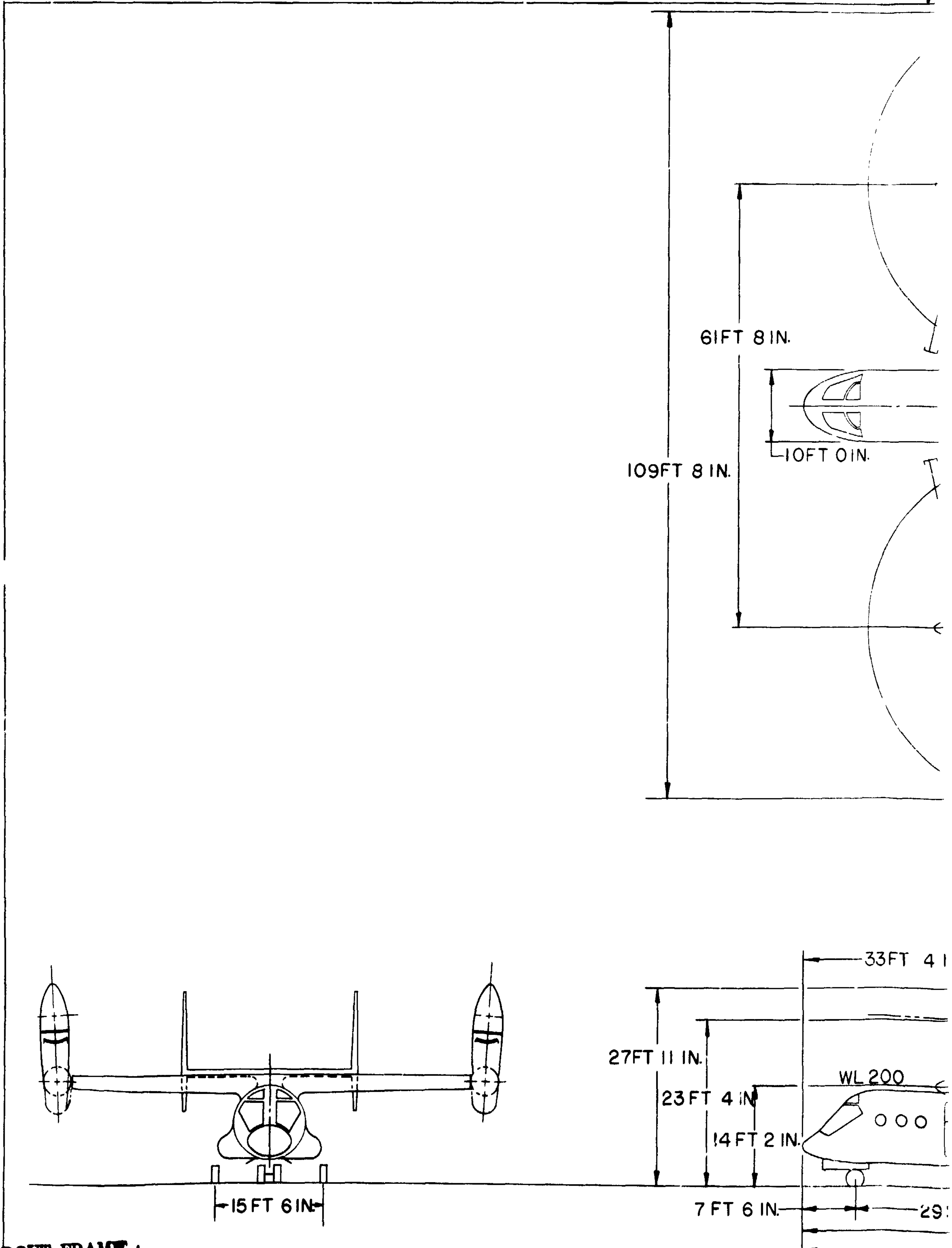
A wing loading of 80 psf was selected to obtain a maximum lift/drag ratio in the 350-380-knot range at 25,000 to 30,000 feet altitude. This wing loading also minimizes sensitivity to gusts. The wing span was selected to provide clearance of the proprotors with the fuselage. This resulted in a wing aspect ratio of 6.9.

A twin installation was selected using the Lycoming 6000 shp version of the LTC4V-1 engine. The 5000 shp version of this engine has been run. Specific fuel consumptions are somewhat lower than the advanced UTTAS engine. The LTC4V-1 with a take-off rating of 6000 shp can be available within the time frame (1980-1985) proposed for the D302. This engine meets the FAA single engine takeoff requirements at 44,100 pounds gross weight as discussed in Section III. Twin engine power available is sufficient for maximum speeds up to 370 knots.

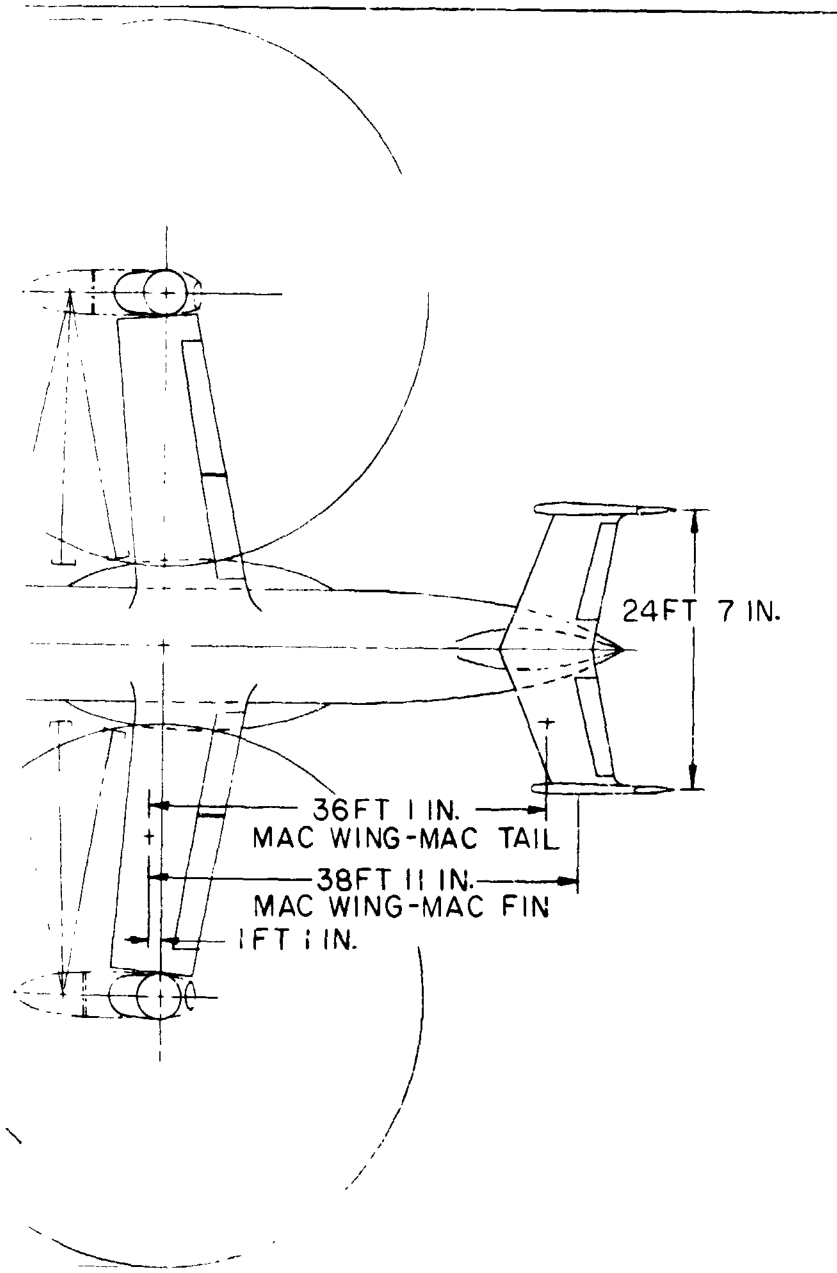
A single engine in each pylon pod offers a simple and aerodynamically clean installation affording easy access to both sides of the engine. Smaller twin engines, in each pylon pod, would compromise both of these desirable features and in addition would complicate the transmission configuration with the additional "twinning" gears and free-wheeling unit required for single-engine operation. The pressurized fuselage of the D302, as a commercial short-haul transport, will accommodate 40 passengers. With an alternate military-type cargo fuselage, up to 68 troops could be carried with a maximum-density seating arrangement.

The basic configuration of the D302 uses growth versions of all concepts that will be proven during the Model 300 flight research development program. These include:

- The stiff wing and stiff inplane gimballed rotor for satisfactory placement of proprotor/pylon/wing frequencies.
- The conversion system using actuators with separate hydraulic motor and systems and mechanically interconnected.
- The advanced technology used in designing the transmissions.
- The power management system which, in helicopter mode, uses the engine power-turbine governor to maintain proprotor rpm by increasing or decreasing power as changes are made in collective pitch. In airplane mode, this system uses a proprotor governor that changes proprotor pitch to maintain selected proprotor rpm.
- The wing flap, flaperons, control systems and phasing boxes, and the H-tail configurations which are all basic configurations that will be developed on the Model 300.

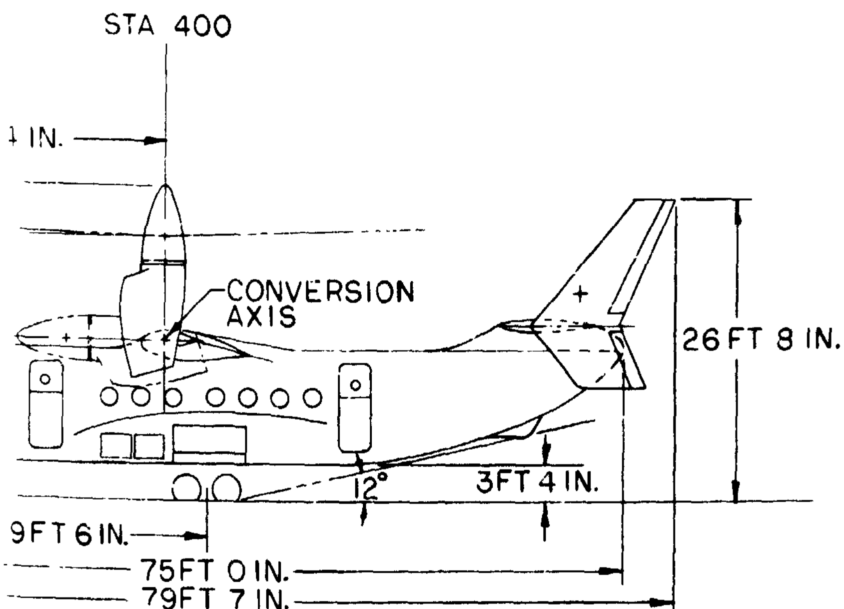


FOLDOUT FRAME 1



CHARACTERISTICS

WEIGHTS	
MAXIMUM OVERLOAD	MILITARY
MAXIMUM GROSS	FAA
LANDING GROSS	
EMPTY	
POWER PLANT	
MANUFACTURER & MODEL	LYCOMING
1 MINUTE POWER	(1000 FT, 95°F, 2 X
10 MINUTE POWER	(SEA LEVEL, STD, 2 X
POWER LOADING	(FAA GROSS WT., 10
PROPROTOR	
TYPE	
DIAMETER	
DISC AREA/ROTOR	
DISC LOADING	(44,100 LB GROSS
BLADE AIRFOIL	THEORETICAL ROO
	TIP
BLADE CHORD	
SOLIDITY	
BLADE TWIST-EFFECTIVE	
TIP SPEED	HELICOPTER MODE
	AIRPLANE MODE
WING	
SPAN	(BETWEEN ROTOR C
AREA	
WING LOADING	(44 100 LB GROSS
ASPECT RATIO	
AIRFOIL	
EMPENNAGE	
HORIZONTAL TAIL	AREA
	ASPECT RATIO
VERTICAL TAIL	AREA - TOTAL
	ASPECT RATIO
DESIGN CRITERIA	
OPERATING SPEED EAS	HELICOPTER MODE
	AIRPLANE MODE
TRANSMISSION RATING (EACH)	ROTOR OUTPUT AT 3
	ENGINE INPUT AT 3
LIMIT LOAD FACTORS	
HELICOPTER MODE	2.0 G (AT 44100
AIRPLANE MODE	3.0 G (AT 44100



FOLDOUT FRAME 1

	MILITARY	58511	LB
	FAA	44100	LB
		44100	LB
		29971	LB
	LYCOMING	LTC4V-1	
	(1000 FT, 95°F, 2 X 5750)	11500	SHP
	(SEA LEVEL, STD, 2 X 6000)	12000	SHP
	(FAA GROSS WT., 10 MIN. PWR)	3.7	LB/HP
		SPRING-RESTRAINED	GIMBAL
		48	FT
		1810	SQ FT
	(44,100 LB GROSS WT)	12.2	LB/SQ FT
	THEORETICAL ROOT	NACA 64-935	a = 0.3
	TIP	NACA 64-208	a = 0.3
		30	IN.
		0.10	
VE		45	DEGREES
	HELICOPTER MODE	800	FT/SEC
	AIRPLANE MODE	520	FT/SEC
	(BETWEEN ROTOR CENTERS)	61.7	FT
		551	SQ FT
	(44 100 LB GROSS WT)	80	LB/SQ FT
		6.9	
		NACA 64A221	MODIFIED
	AREA	200	SQ FT
	ASPECT RATIO	3.02	
	AREA - TOTAL	210	SQ FT
	ASPECT RATIO	2.64	
	HELICOPTER MODE	140	KT
	AIRPLANE MODE	300	KT
S (EACH)	ROTOR OUTPUT AT 318 ROTOR RPM	4250	HP
	ENGINE INPUT AT 318 ROTOR RPM	5750	HP (SINGLE ENGINE)

2.0 G (AT 44100 LB GROSS WT)
3.0 G (AT 44100 LB GROSS WT)

DESIGN LAYOUT

D302 TILT-PROPROTOR CONCEPTUAL DESIGN

DESIGNER 2-18-72 D302-960-001

FOLDOUT FRAME

III. CIVIL TRANSPORT APPLICATION

The D302 was analyzed for commercial VTOL short-haul operations. The relevant specification used was the FAA Tentative Airworthiness Standards for Powered Lift Transport Category Aircraft, August 1970. For the critical takeoff performance, these standards call for a 150-foot-per-minute rate of climb at V_1, with one engine inoperative. For the D302 operating on a 95°F summer day at a gross weight of 44,100 pounds, the required rate of climb is estimated to be met at 45 knots EAS at an altitude of 1000 feet using the one-minute rating on the operative single engine. The D302 will reach 60 knots EAS in approximately the first ten seconds of this one-minute rating. At this airspeed, V_2, a climb rate of 200 feet per minute can be achieved with the ten-minute rating of the single engine. This would allow a go-around for a cyclic-flare, roll-on landing at a moderate-size vertiport. Such an operation would be considered as a "standard takeoff" operation and defined the FAA maximum gross weight for the D302 at +44,100 pounds. For takeoff from small pads, the aircraft climbs rearward to a critical height (critical decision point) verified by flight tests. At this point, should an engine failure occur, the aircraft can return to the pad for a cyclic flare landing using the one-minute engine rating, or can accelerate to V_2 for climb-out and go-around with the ten-minute engine rating. This type of takeoff can be considered as a "vertical" takeoff operation at the same maximum gross weight. Calculations of critical decision point height for the D302 vertical takeoff mode or minimum vertiport size for the "standard" takeoff mode are beyond the scope of the Task I effort but should be comparable to helicopter requirements in similar operations.

With the tilt-proprotor concept, a further option is available to the pilot after V_2 is reached with one engine inoperative. A conversion to proprotor mode can be made, and at 200 knots EAS a climb rate of 500 feet per minute can be achieved at maximum continuous rating on the single engine.

This performance enables the D302 to operate with safety on summer days in the Northeast corridor and the West Coast short-haul markets. A typical short-haul mission profile is summarized in Table III-I and is the basis for payload and productivity analyses discussed below. The passenger capacity is forty and typical range capability is 400 nautical miles at 348 knots, 30,000 feet, with reserves. While a fully-mature, high-patronage second-generation system should require vehicles of much greater passenger capacity and multi-engine installations, the economic success of the initial operational system will depend on maintaining reasonable passenger load factors and utilization during the period when patronage is being developed. For the 1980-1985 time period, the capacity of the D302 is believed to be ideal.

TABLE III-I. COMMERCIAL VTOL AIRCRAFT MISSION PROFILE

A. Hot Day Operation

1. Preflight service aircraft, load for outbound leg, 10 minutes.

2. Warm-up, two minutes at power for 70 percent gross weight lift at 100 percent hover rpm (HRPM), 1000 feet, 95°F

3. Takeoff at normal gross weight, one minute at hover OGE power at 100 percent HRPM, 1000 feet, 95°F

4. Accelerate and climb to 2000 feet above terrain (to 3000 feet, 95°F) using 100 percent HRPM and power for noise abatement climb of either:

   a) straight climb at 1800 feet per minute, 60-knot airspeed; or,

   b) 30 degree-bank turning climb at 1800 feet per minute, 60-knot airspeed

5. Accelerate from 60 knots to 200 KEAS while converting to proprotor mode with NRP available at 90 percent HRPM and 3000 feet, 95°F. (Fuel equivalent, 3 minutes at NRP)

6. Climb on course to specified cruise altitude at 200 KEAS using maximum available torque, 90 percent HRPM and MIL-STD-210A atmosphere above 5000 feet

7. Cruise with 95 percent continuous torque available (engine or transmission) for specified time at 75 percent HRPM and MIL-STD-210A hot atmosphere

8. Descend on course at 2000 feet per minute to 2000 feet above terrain (to 3000 feet, 95°F) at 200 KEAS, 75 percent HRPM (assuming MIL-STD-210A hot atmosphere above 5000 feet.) Clear local noise-sensitive high terrain by 1000 feet.

9. Decelerate from 200 KEAS to 100 knots while converting to helicopter mode with 20 percent NRP available at 90 percent HRPM and 3000 feet, 95°F. (Fuel equivalent, 3 minutes at flight idle)

10. Descend and decelerate from 3000 feet, 95°F to 1000 feet, 95°F using noise abatement descent profile, 100 percent HRPM, airspeed 60 knots. (Fuel equivalent, 1.5 minutes at flight idle)

TABLE III-I. Concluded

11.	Land, unload, load passengers to seating capacity or normal gross weight with rotors turning; no refuel, six minutes. (Fuel equivalent two minutes at flight idle)
12-19.	Repeat 3 through 10
20.	Arrive at this point with at least 45 minutes fuel remaining based on proprotor cruise at 200 KEAS, 75 percent HRPM
21.	Land, stop rotors, unload, post-flight service aircraft, 15 minutes
B.	Standard Day Operation
	As (A) above except substitute standard temperature for 95°F and MIL-STD-210A hot atmosphere.

The inboard profile layout, Figure III-1, is based on a conventional single 21-inch aisle arrangement with four abreast seating based on 21-inch seat widths and 36-inch pitch. In keeping with relatively simple passenger accommodations, one lavatory and space for an automatic snack-beverage dispenser are provided near the forward entrance. Carry-on luggage racks and coat racks are provided immediately to the right of both forward and aft entrance doors on opposite sides of the aisle. Additional space for luggage is provided in pressurized compartments in the wheel-well fairings and under the seats. The layout is arranged to accommodate the required Type II and Type III emergency exits for crew and passengers. At maximum passenger capacity, a jump seat is available for the cabin attendant at the rear of the pressurized cabin. Crew compartment visibility is provided to be compatible with steep descent operations desirable for minimizing ground exposure to aircraft noise.

Performance and noise characteristics relevant to the commercial short-haul mission are described in the remainder of this section.

A. PAYLOAD RANGE

A typical short-haul flight on a hot day (95°F at takeoff, MIL-STD-210 (hot) at altitude) carries forty passengers from New York to Washington and from Washington to New York without refueling. Airspeed at 95 percent power is 348 knots at an altitude of 30,000 feet. The single leg range extends to 670 nautical miles and enables thirty-three passengers to be carried from New York to Atlanta or New York to Chicago. Representative city-pairs in the payload-range envelope are shown in Figure III-2.

B. PRODUCTIVITY

The productivity was analyzed for trips from 50 to 325 nautical miles radius. The cruise speed used was slightly faster than best-range speed. Cruise altitude was selected for minimum fuel consumption. New York to Washington passenger trip time (between V-port terminals) is estimated at 1.05 hours. Aircraft round trip time without refueling is 2.4 hours and aircraft productivity is 570 ton-knots. Results are shown in Figure III-3.

C. TAKEOFF AND APPROACH PROFILES

Takeoff and approach profiles were selected to minimize noise around the terminal area. Steep gradients of 16 to 18 degrees, as shown in Figure III-4, far steeper than possible with CTOL aircraft, provide ample height clearance over noise-sensitive areas, yet the final approach to the touchdown area can be as shallow as 3 to 4 degrees. Piloting tasks associated with steep gradients are eased by rotary-wing control capabilities, but confirmation and acceptance by pilots requires more operational experience. This is considered to be a high-priority subject for the research aircraft flight investigations. The takeoff path has an average gradient of 16 degrees, based on a climb of 1800 feet per minute at 60 knots. The aircraft reaches an altitude of 1750 feet one nautical mile from the terminal and the noise level directly beneath this point is estimated at 85 PNdb.

D. NOISE FOOTPRINT

Steep gradient profiles, plus the combination of low disc loading (~12 psf) and moderate tip speed (800 fps) result in a small noise footprint. The level for a 50-foot hover is estimated to be 95 PNdb at 500 feet. Due to a downward directivity pattern for rotor-generated noise, the 95 PNdb contour for takeoff is estimated to extend 2900 feet from the center of the landing pad along a straight climb-out path and is reduced to 2500 feet in a climbing turn. Maximum sideline noise levels, as the aircraft flies by, are shown in Figure III-5.

E. GENERAL NOISE COMPARISON

The calculated noise of the D302 is compared in Figure III-6 with calculated levels of higher disc-loading, sixty passenger, VTOL aircraft proposed for short-haul service and with measured levels of present-day helicopters and common surface transportation vehicles. These curves confirm that low disc loading VTOL aircraft will be least noisy, while jet types will be the noisiest. Additionally, the noise of the D302 in takeoff mode will be about the same as that of medium helicopters operating today at airspeeds below about 80 knots and ill be no greater, at typical distances to each, than that generated by heavy commercial surface vehicles. In cruise mode, the flyover noise of the D302 will be lower than those produced by the smallest helicopters, and at typical flyover altitudes, will be comparable to background levels measured in areas with passenger car traffic. The D302 will be socially acceptable when operating in and over populated areas. The internal noise level will be very low. The location of the engines and transmission far removed from the cabin area will make the D302 much quieter than helicopters in that mode of flight. The very low cruise tip speed and the remoteness of engines and transmissions will make the internal noise in cruise mode much lower than a turboprop airplane.

F. ECONOMICS OF SHORT-HAUL COMMERCIAL AIR TRANSPORT

1. Economic Premise for VTOL

Present commercial air transport reached saturation levels at major airports in 1968-1969. The return of normal business growth rates will cause a return of even greater congested conditions. Without drastic improvements to the ground control and related facilities, this will mean increased costly delays for CTOL operations. The introduction of a VTOL short-haul commercial aircraft system, with V-ports close to traffic origination centers and away from CTOL ports, can reduce delays and thereby save time and money for airlines and passengers. The total life cycle system costs of a VTOL system should, therefore, be compared to other alternatives for reducing delays due to future congestion. While the comparison of total life-cycle system costs are beyond the scope of Task I, it is believed that the cost of adding a tilt-proprotor VTOL short-haul under-saturated system to the CTOL system will be more economical than adding CTOL runways and vastly improved air traffic control facilities to fend off saturation and enable CTOL to handle the total short-haul and long-haul traffic of the 1980's.

2. Economic Analysis of Short-Haul Civil Aircraft

The operating costs of the 40-passenger D302 VTOL were estimated and are compared in Table III-II, with a typical short-haul airliner (80-passenger DC-9) operating on a short-haul journey between New York City and Washington, D.C. The operating cost estimate for both the D302 and the DC-9-type aircraft was based on airline operating experience for the fixed-wing items and on Bell experience for the rotary-wing items. The direct operating cost for the 40-passenger D302 was estimated to be 93 percent of that for the 80-passenger DC-9. The cost of a typical short-haul journey (New York City to Washington, D.C.), based on a 20-percent return on aircraft investment and a 50-percent load factor, was calculated to be $37.45 for VTOL and $25.25 for CTOL (at zero delay). The estimate for the CTOL delay cost included the cost of reduced block-speed and of introducing extra aircraft to retain the same frequency of service. For a ten-minute delay per one-way journey, such as is believed to be scheduled for the present (1972) New York City-Washington, D.C. air shuttle, the CTOL fare increased to $28.36. These CTOL estimates were found to be close to actual 1972 fares, based on 100-passenger DC-9 aircraft. Thus, the analysis is believed valid. Ground transportation was then included to obtain total one-way journey cost and time. Results indicate that for the present ten-minute CTOL delay level, the VTOL passenger will save 0.69 hours (41 minutes) at an additional cost of $2.04. The passengers' time value for equal journey cost is thus $2.96 per hour. As CTOL delays increase, the CTOL fare must increase; and it is estimated that for delays above 17 minutes, not only the VTOL-journey time, but the cost will be lower. Thus, if the present delay of ten minutes increases by more than seven minutes, the VTOL system, with the assumptions herein and at zero delay, will offer more economical service to all passengers regardless of their time value.

If vastly improved air traffic control and related facilities are installed to prevent CTOL delays from increasing above current levels, then a passenger would still prefer, on an economic basis, to fly VTOL if his time is valued at or above $2.96 per hour.

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TABLE III-II. COST ANALYSIS FOR TYPICA

GENERAL	LINE	DETAIL ITEM	
Aircraft Description	1	Design gross weight	poun
	2	Weight empty	poun
	3	Passenger capacity	numb
	4	Cruise speed at altitude, design	knot
	5	Purchase price, including spares	mill
Maintenance Manhours	6	Airframe and avionics	manh
	7	Engines	
	8	Transmission and shafting	
	9	Proprotors, rotating controls	
	10	Servicing	
	11	Total Labor Maintenance Required	manh
	12	Total Labor Cost at $15 per man hour including overhead	$/bl
Maintenance Part Cost	13	Airframe and avionics	$/bl
	14	Engines	
	15	Transmission and shafting	
	16	Proprotors, rotating controls	
	17	Proprotor blade retirement, at 10,000 hours	
	18	Total Maintenance Parts Costs	$/bl
Operating Costs	19	Total maintenance, parts and labor	$/b
	20	Crew	
	21	Fuel at $0.015 per pound	
	22	Depreciation, 30,000 hours, 30-percent residual	
	23	Insurance, 2500 hours per year, 2-percent per year	
	24	Total Operating Cost	$/b
Daily Flight Schedule	25	Scheduled allowance for delays, per one-way trip	min
New York City to Washington, D.C.	26	Aircraft round trip time	hou
	27	Number round trips per 12-hour day	num
	28	Number one-way trips per 12-hour day	
	29	Passengers per aircraft at 50-percent load factor	
	30	Passenger one-way trips per day per aircraft	
	31	Number aircraft required per 1000 passengers per day	num
	32	Aircraft ground taxi time, one-way journey	hou
	33	Aircraft flight time, one-way journey	
	34	Aircraft block time, doors closed-doors open	hou
Air Trip Cost One Way	35	Direct operating cost, one-way journey	$/p
	36	Capital return on aircraft and spares, 20-percent per year	
	37	Indirect airline cost	
	38	Terminal usage fees	
	39	Total Air Fare (Less Federal Tax)	$/p
Ground Journey	40	Taxi-cab average distance, total per flight	mil
	41	Taxi-cab average time, total per flight	min
	42	Taxi-cab cost, total per flight	$/p
Total Cost	43	Total One-Way Cost (Ground and Air)	$/p
Comparison Time and Cost	44	Passenger air trip time, airport terminal to airport terminal	hou
	45	Passenger one-way trip time, ground & air	
	46	Time saved by VTOL, per one-way trip	hou
	47	Extra cost for VTOL, per one-way trip	$/p
	48	Passenger Time-Value for Equal Cost	$/

*VTOL is faster

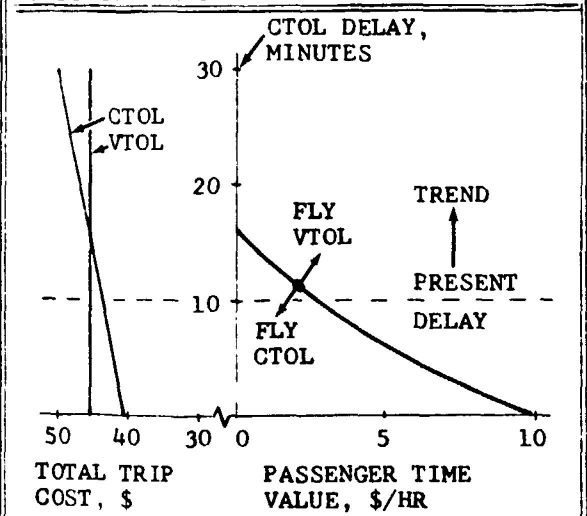
ALYSIS FOR TYPICAL SHORT-HAUL TRIP

	UNITS	D302 VTOL	DC-9 TYPE CTOL
	pounds	44100	77700
	pounds	29355	45300
	number seats	40	80
	knots	348	472
	millions $	4.05	5.04
	manhrs/block hr	3.38	4.76
		1.59	2.0
		0.92	-
		1.00	-
		0.45	0.45
	manhrs/block hr	7.34	7.21
head	$/block hour	110.1	108.1
	$/block hour	14.2	19.5
		33.6	41.6
		17.3	-
		24.6	-
		9.2	-
	$/block hour	98.9	61.1
	$/block hour	208.9	169.2
		112	117
		34	70
		95	112
		32.4	41
	$/block hour	482.3	519.2

Air Fare Cost, (39)

$= (20\% \times (5) / 365 \times (30)) + ((24) \times (34) / (3) \times 50\%) + (37) + (38)$

Circled numbers indicate line number.



	minutes	0	0	10	20	30	40
	hours	2.22	2.55	2.88	3.21	3.54	3.87
	number	5.41	4.71	4.17	3.74	3.39	3.1
\		10.82	9.42	8.34	7.48	6.78	6.2
		20	40	40	40	40	40
		216	377	334	299	271	248
y	number	4.63	2.65	3.0	3.34	3.69	4.03
	hours	-	0.16	0.16	0.16	0.16	0.16
		0.87	0.79	0.96	1.12	1.29	1.46
	hours	0.87	0.95	1.12	1.28	1.45	1.62
	$/passenger	20.98	12.33	14.54	16.61	18.82	21.03
er year		10.27	7.32	8.27	9.23	10.19	11.13
		5.00	5.00	5.00	5.00	5.00	5.00
		1.20	0.60	0.60	0.60	0.60	0.60
	$/passenger	37.45	25.25	28.41	31.44	34.61	37.76
	miles	10.0	20.0	20.0	20.0	20.0	20.0
	minutes	20.0	40.0	40.0	40.0	40.0	40.0
	$/passenger	8.20	15.20	15.20	15.20	15.20	15.20
	$/passenger	45.65	40.45	43.61	46.64*	49.81*	52.96*
t terminal	hours	1.05	1.23	1.40	1.56	1.73	1.90
		1.38	1.90	2.07	2.23	2.40	2.57
	hours	-	0.52	0.69	0.85	1.02	1.19
	$/passenger	-	5.20	2.04	-0.99	-4.16	-7.31
	$/hour	-	10.00	2.96	-1.16	-4.08	-6.14

*VTOL is faster AND MORE ECONOMICAL for scheduled delays above 17 minutes per journey.

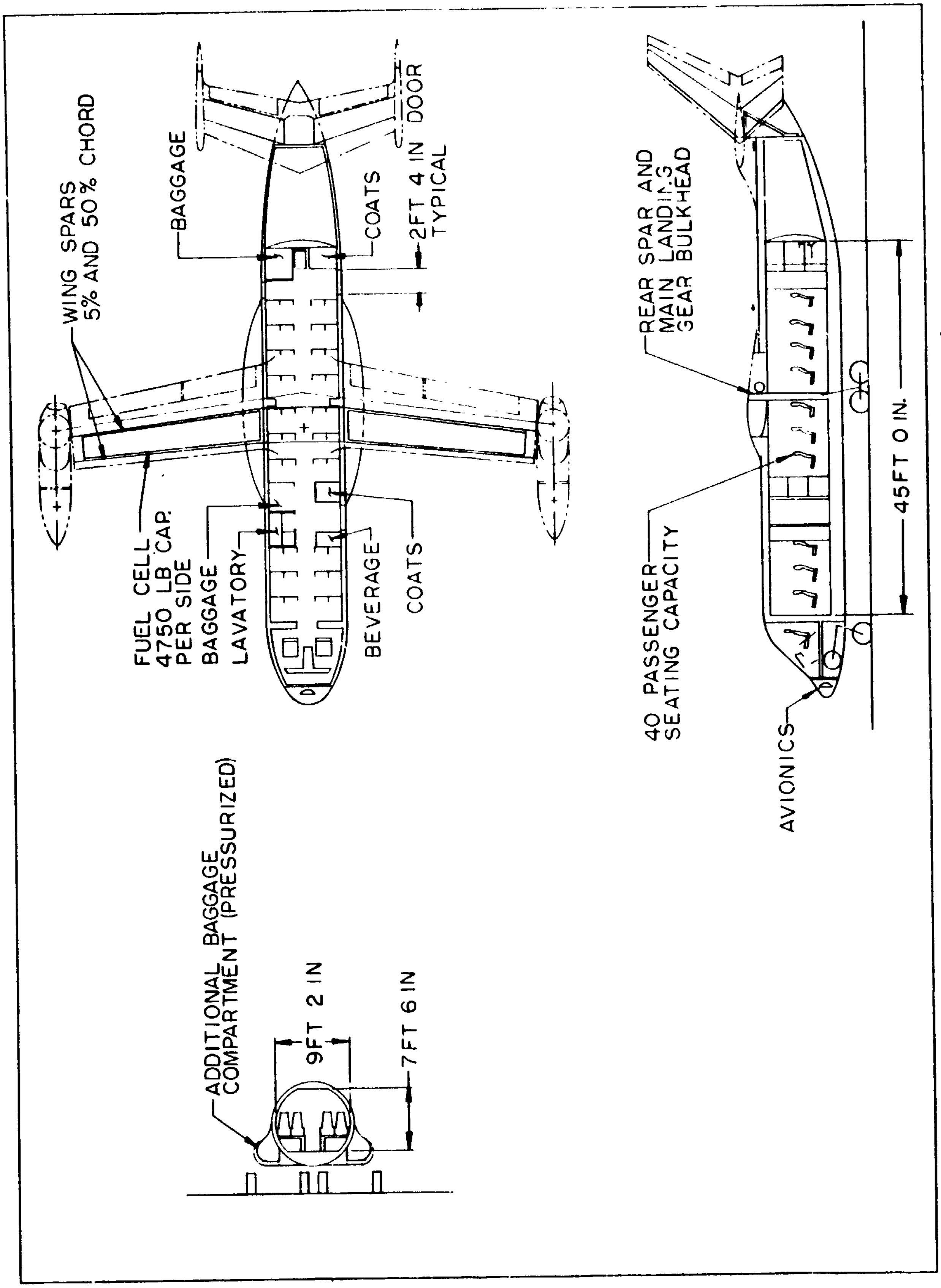


Figure III-1. Inboard Profile Layout.

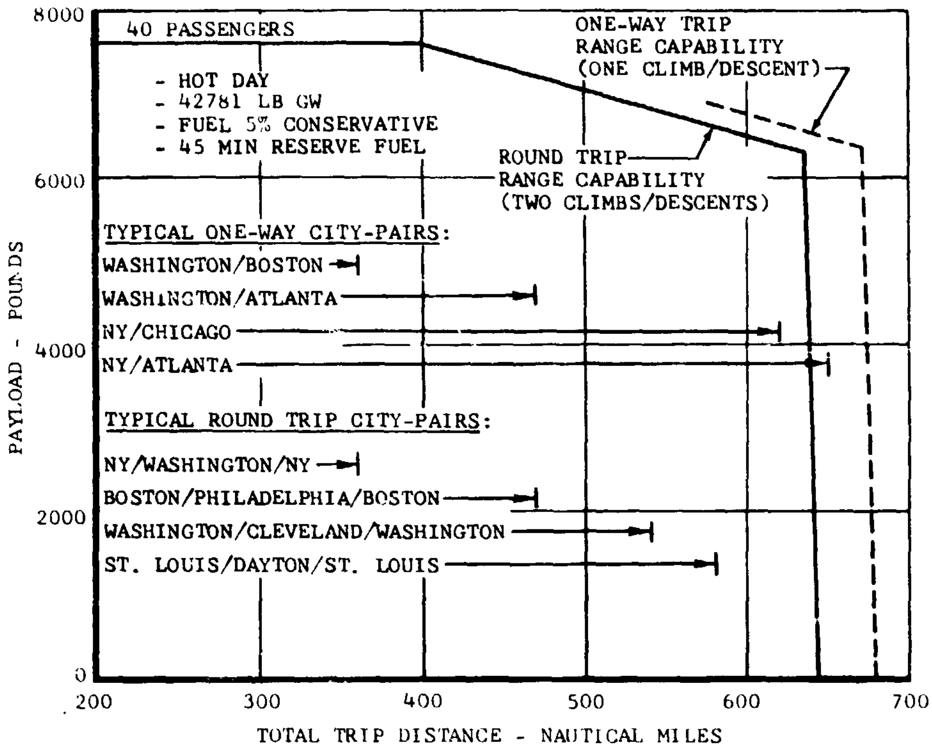


Figure III-2. Payload-Range, Civil Transport.

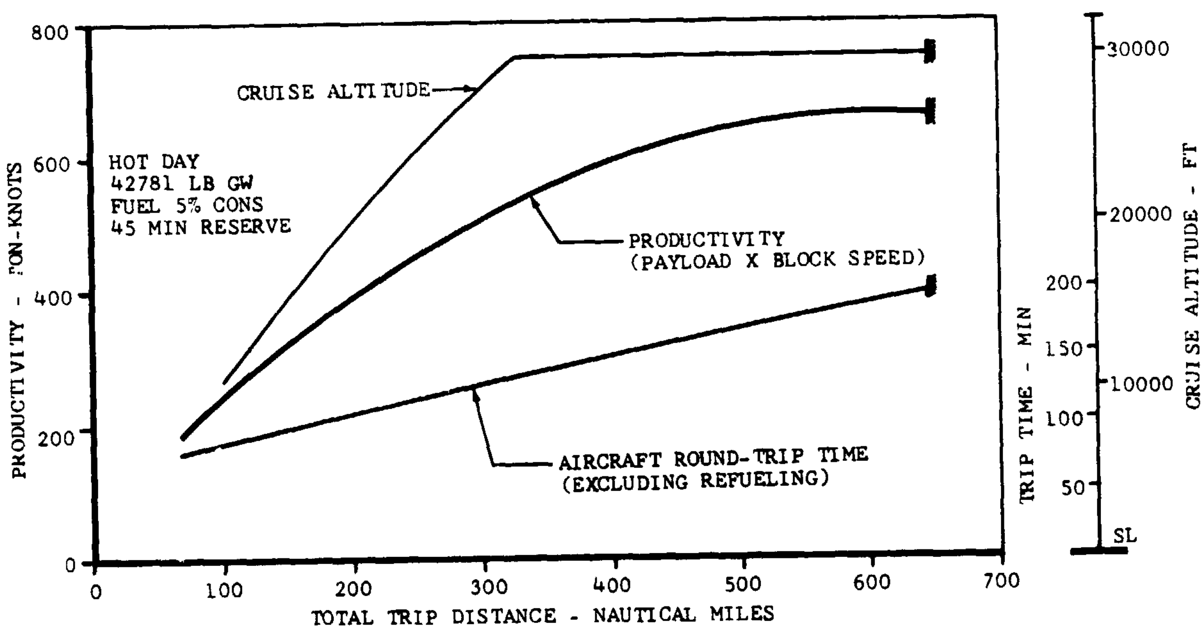


Figure III-3. Productivity-Range, Civil Transport.

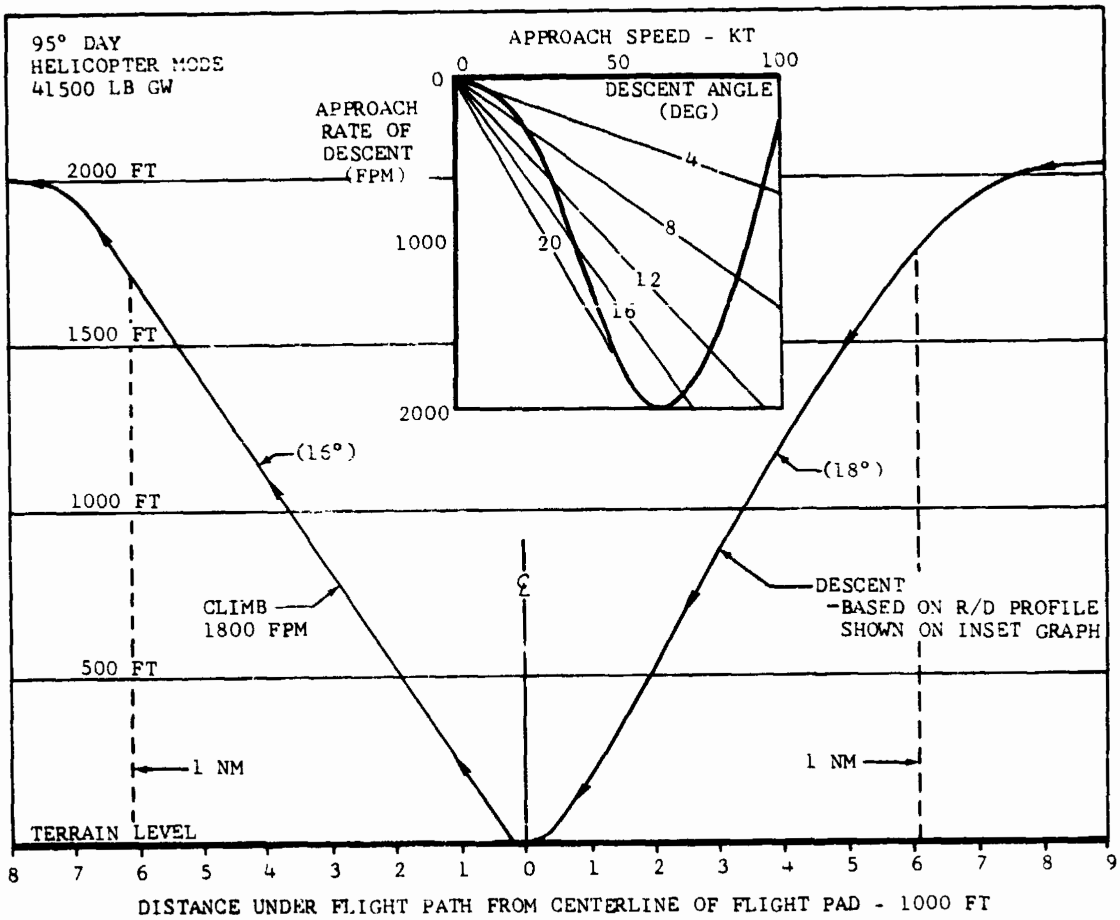


Figure III-4. Takeoff and Approach Profiles, Civil Transport.

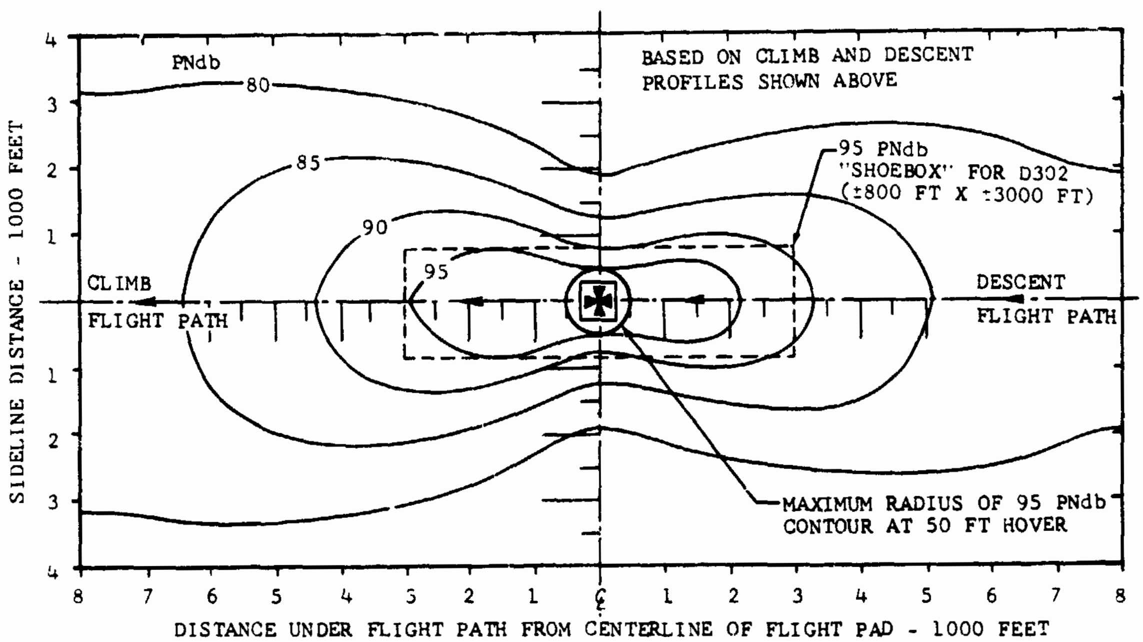


Figure III-5. Noise Footprint, Civil Transport.

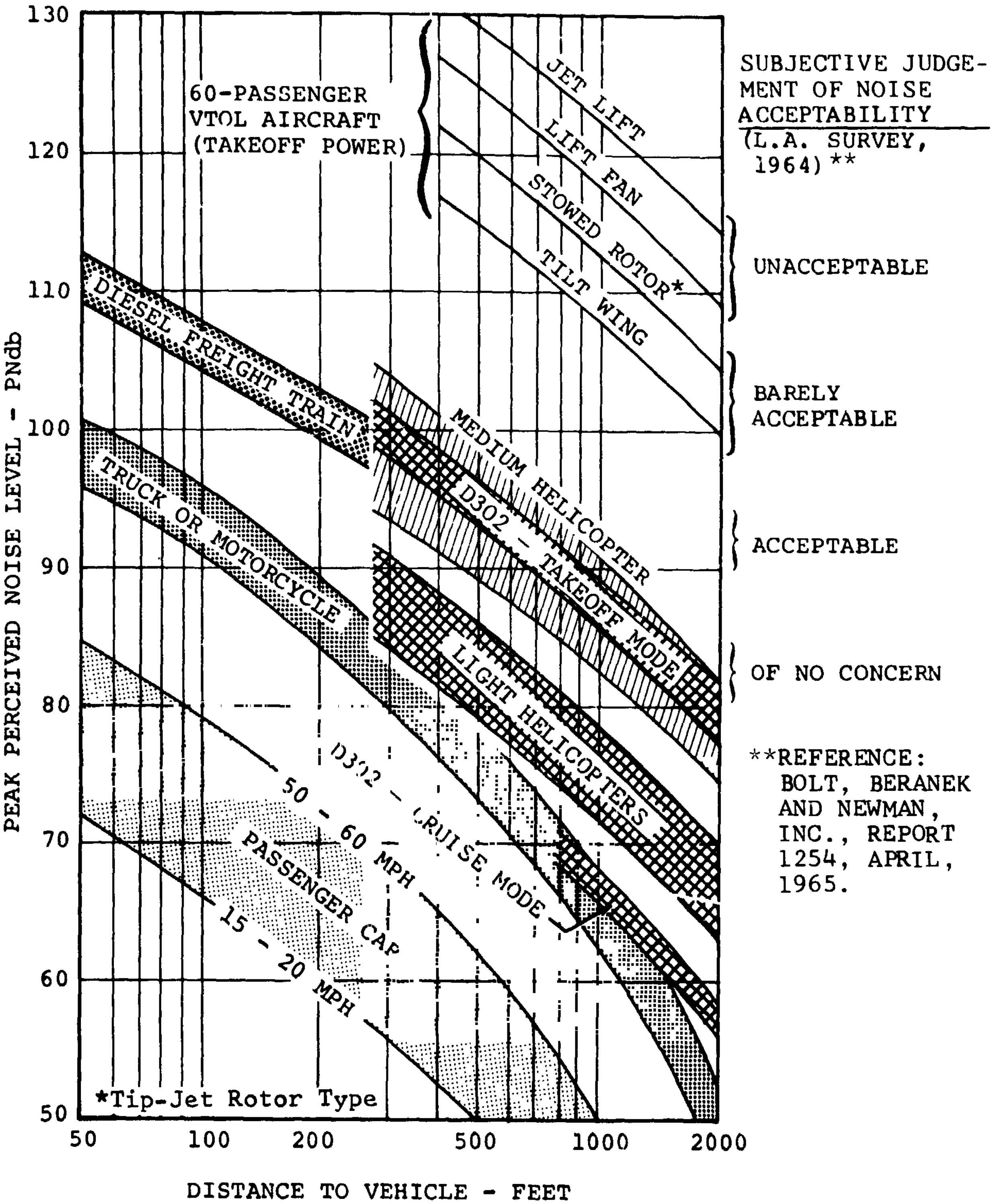


Figure III-6. General Noise Comparison.

IV. MILITARY MISSION APPLICATIONS

A. AIRCRAFT CONFIGURATIONS

The D302 can perform a variety of military missions such as: troop transport, rescue, tactical transport, and flying crane. Some of the possible internal arrangements for performing these missions are shown in Figure IV-1.

Troop-transport could be performed with a high density seating arrangement as shown in Figure IV-1(a). Four doors are provided, two on each side of the cabin. A center-line bench type seating arrangement will accommodate 48 troops. Seat width is 22 inches with foldable end seats to permit cross-aisle loading from one side when necessary. The pressurized cabin permits cruising at high altitudes on long-range missions.

The internal arrangement shown in Figure IV-1(b) shows a wide door on one side of the aircraft for rescue missions and for side loading cargo pallets.

In the role of a tactical transport aircraft, the D302 could have a rear ramp as shown in Figure IV-1(c). The fuselage would be rectangular with a cargo clearance internal width of 93 inches and a wall-to-wall width of 113 inches. The cargo compartment would be 42 feet 6 inches long and 78 inches high. High density seating will accommodate up to 68 troops. This configuration would not be pressurized. Table VI-II shows a fuselage weight increase of 800 pounds over the round-bodied pressurized transport configuration.

Both fuselage configurations of the D302 aircraft could have provisions for sling loads to perform flying crane-type missions.

B. MISSION PROFILES

Capability of the D302 for long-range transport missions is illustrated in Figures IV-2 and IV-3. Flight profiles are shown for the pressurized fuselage configuration cruising at 30,000 feet. Figure IV-2 shows that 48 troops can be delivered on a 500-nautical mile radius mission with a cruise velocity of 325 knots. At the takeoff gross weight of 51,691 pounds, the aircraft can hover out-of-ground effect at sea level on a 95°F day. At mid-mission, it can hover at 4000 feet on a 95°F day.

Figure IV-3 shows that five tons of cargo can be delivered over a range of 2200 nautical miles. A STOL takeoff is made at a gross weight of 58,511 pounds and the aircraft cruised at 325 knots at 30,000 feet.

Figure IV-4 shows the D302 capability for rescue missions. A 500-nautical mile radius mission is shown with a 30-minute search and a 30-minute hover to pick up six men at a 6000 feet

95°F day condition. Outbound cruise is at 350 knots at 25,000 feet.

A tactical transport mission is shown in Figure IV-5. This mission is flown with the unpressurized rectangular fuselage with the rear cargo ramp. Three rows of seats running the full length of the cargo compartment are used to accommodate 68 troops as shown in Figure IV-1. At a 51,000-pound gross weight, the aircraft can hover out of ground effect at a takeoff condition of 1000 feet 95°F, and cruise out at 250 knots at 10,000 feet to deliver the troops over a 100-nautical mile radius of action. At the delivery point, the hover ceiling is 2000 feet on a 95°F day.

Payload versus radius is shown for the D302 operating as a flying crane in Figure IV-6.

A ferry range of 3550 nautical miles is shown in Figure IV-7. At the takeoff gross weight of 56,500 pounds, the aircraft can make a STOL takeoff or hover in ground effect at sea level on a standard day.

C. COMPARISON OF THE D302 TILT-PROPROTOR AIRCRAFT WITH CHINOOK (CH-47C) HELICOPTER

The size of the D302 conceptual aircraft is compared with the Chinook helicopter in Figure IV-8. The D302 is compared with the CH-47C for a cargo radius mission in Figure IV-9. Takeoff weights for each aircraft are shown at the same out-of-ground effect hover conditions of 3000 feet 95°F. Speeds for each aircraft were best range cruise speed at sea level. The D302 is also shown at 15,000 feet. Payload inbound was half the outbound payload, and reserve fuel was ten percent of the initial fuel load. This figure shows that the D302 can operate over a radius of 400 to 500 nautical miles depending on cruise speed and altitude. At the maximum radius of 168 nautical miles (with normal fuel) of the Chinook, both aircraft can carry approximately 15,000 pounds of payload. However, the D302 is cruising at 250 knots and the Chinook at only 132 knots.

The advantage of speed for the tilt-proprotor aircraft is shown in Figure IV-10 which compares the specific productivity of the two aircraft. Specific productivity is a measure of the rate of moving cargo. It is the payload multiplied by the block speed divided by the operating weight.

The specific productivity of the Chinook peaks at 64 ton-knot per ton at a radius of 100 nautical miles. The higher cruise speed of the D302 enables it to achieve a higher specific productivity of 70 ton-knot per ton at a radius of 200 nautical miles for a sea level cruise. Specific productivity of the tilt proprotor is greater than or equal to the helicopter for mission radii from approximately 75 up to 500 nautical miles.

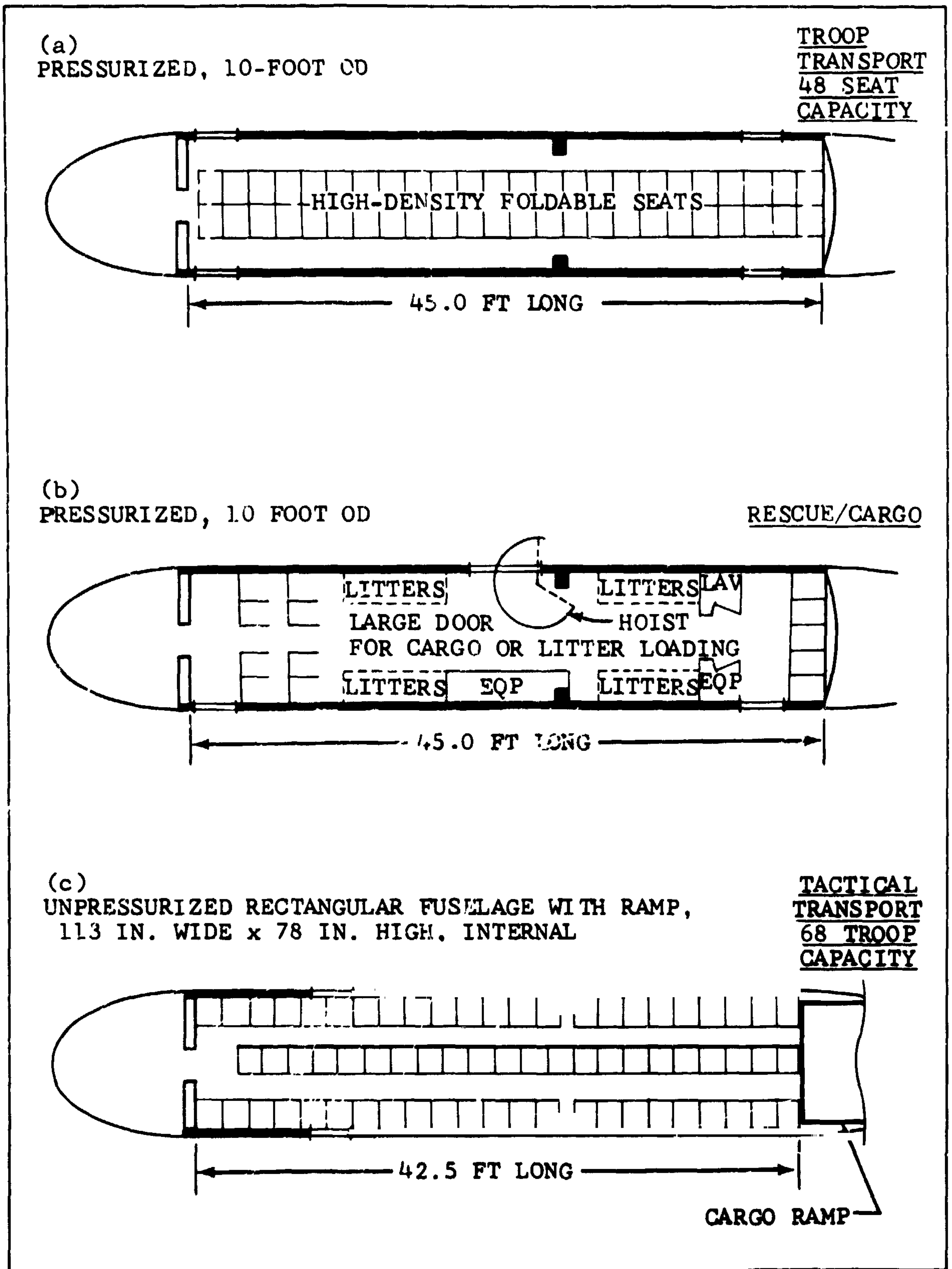


Figure IV-1. D302 Conceptual Aircraft Internal Arrangements for Military Missions.

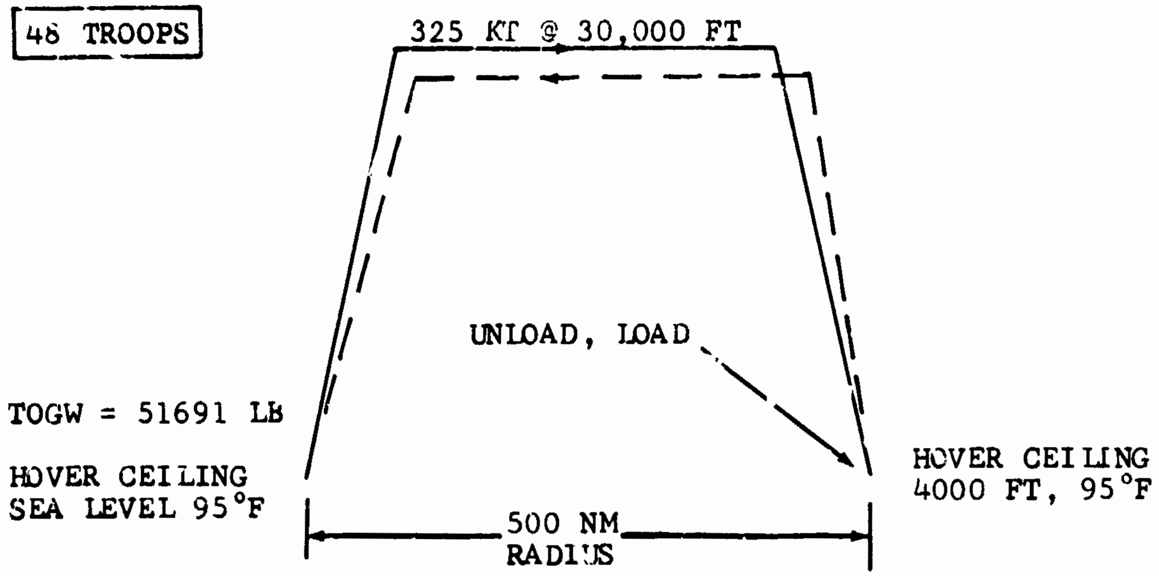


Figure IV-2. D302 Conceptual Aircraft Long-Range Troop Transport Mission.

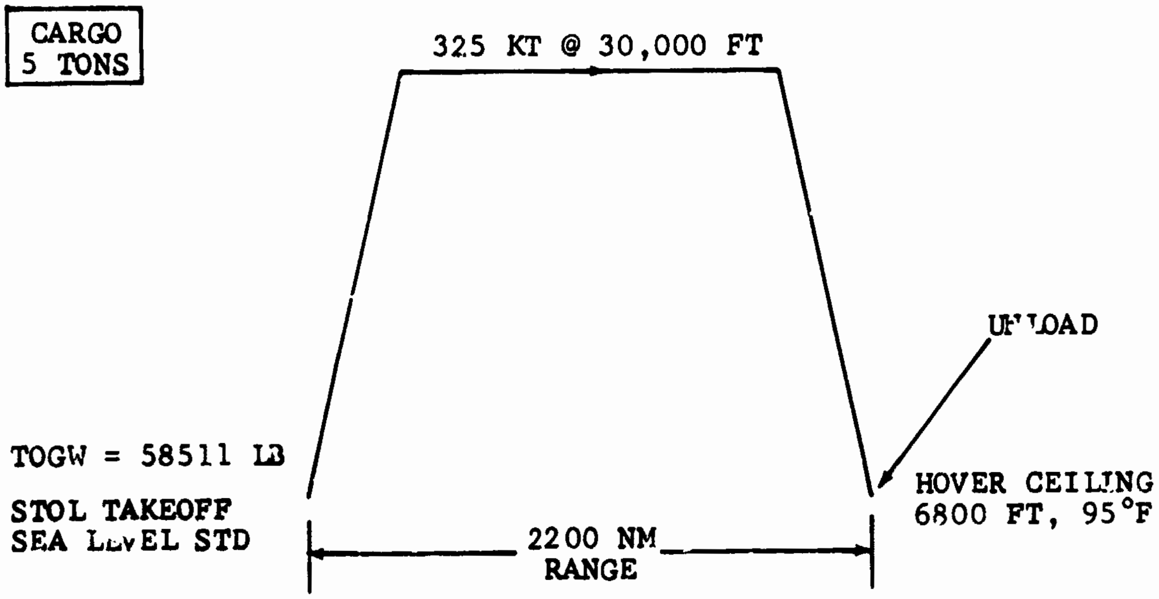


Figure IV-3. D302 Conceptual Aircraft Long-Range Cargo Mission.

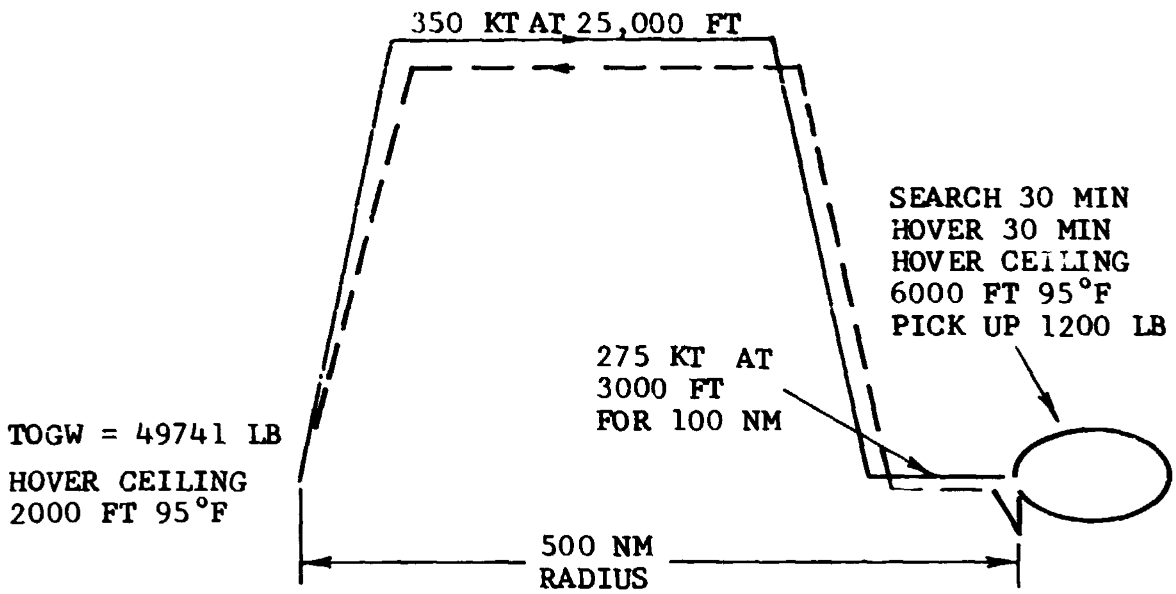


Figure IV-4. D302 Conceptual Aircraft Rescue Mission.

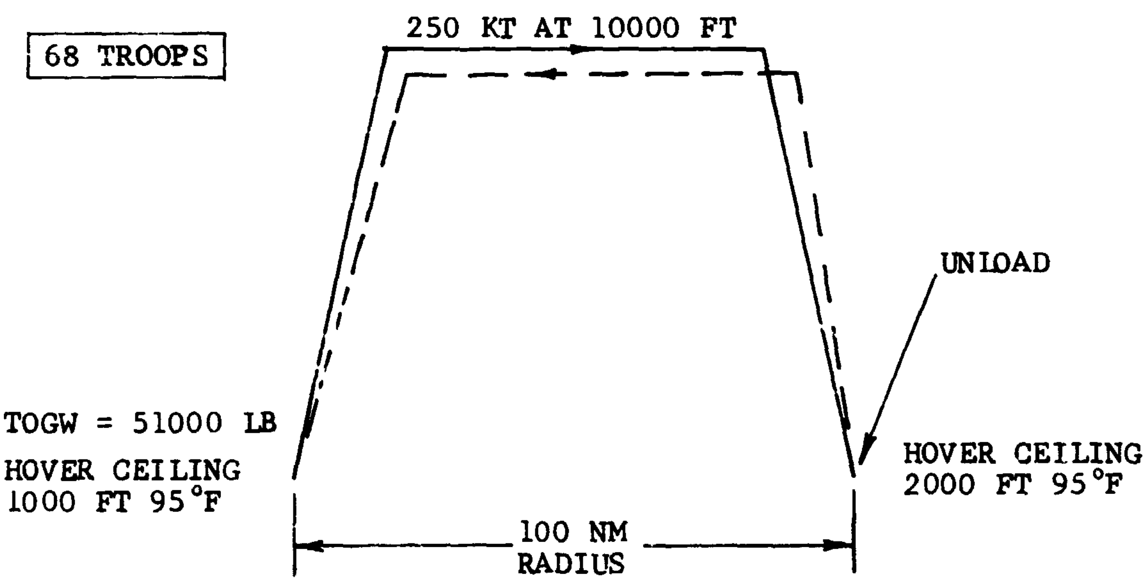


Figure IV-5. D302 Conceptual Aircraft Tactical Transport Mission.

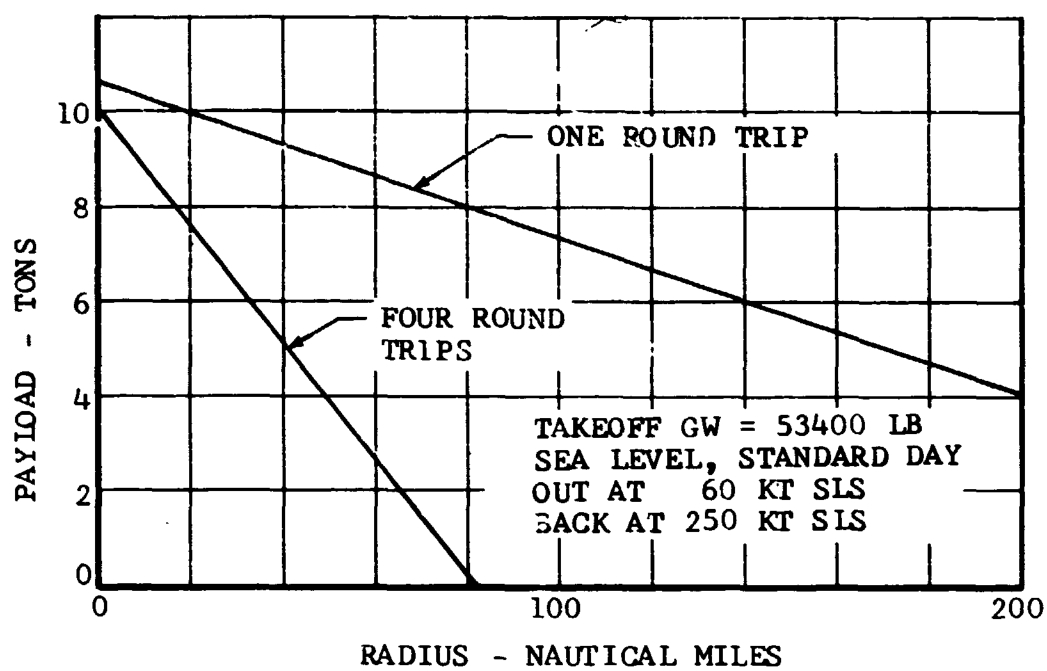


Figure IV-6. D302 Conceptual Aircraft Flying Crane Mission.

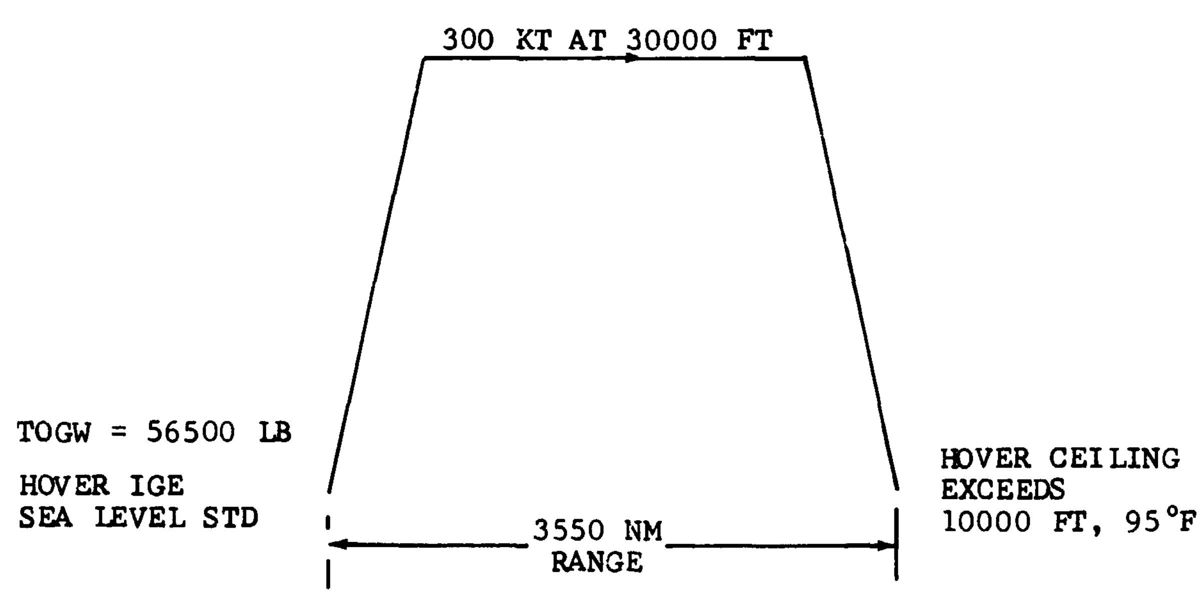
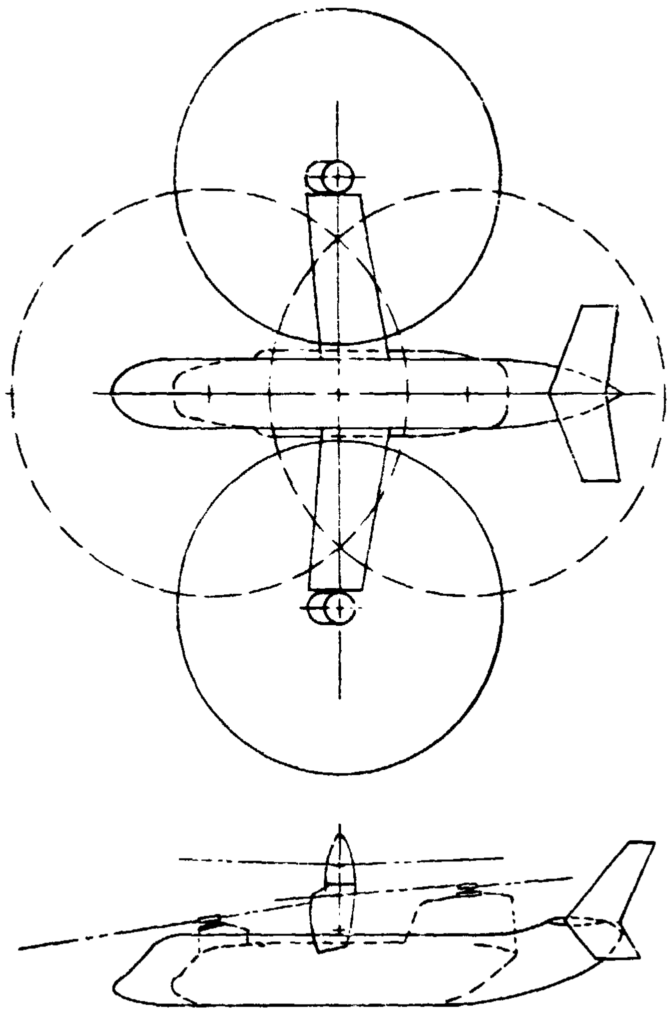


Figure IV-7. D302 Conceptual Aircraft Ferry Mission.



		Bell D302	Chinook CH-47C
Takeoff GW, Hover OGE at 3000 ft 95°F	lb	49000	44000
Operating Weight	lb	30671	21100
Empty Weight	lb	29971	20362
Installed Power, Takeoff, SLS	hp	12000	7500
Maximum Speed	kt	358	132
Rotor Diameter	ft	48.0	60.0
Overall Length	ft	80.0	98.9
Width	ft	109.6	60.0
Height	ft	27.5	19.0

Figure IV-8. Comparison of the D302 Conceptual Aircraft with the Chinook CH-47C Helicopter.

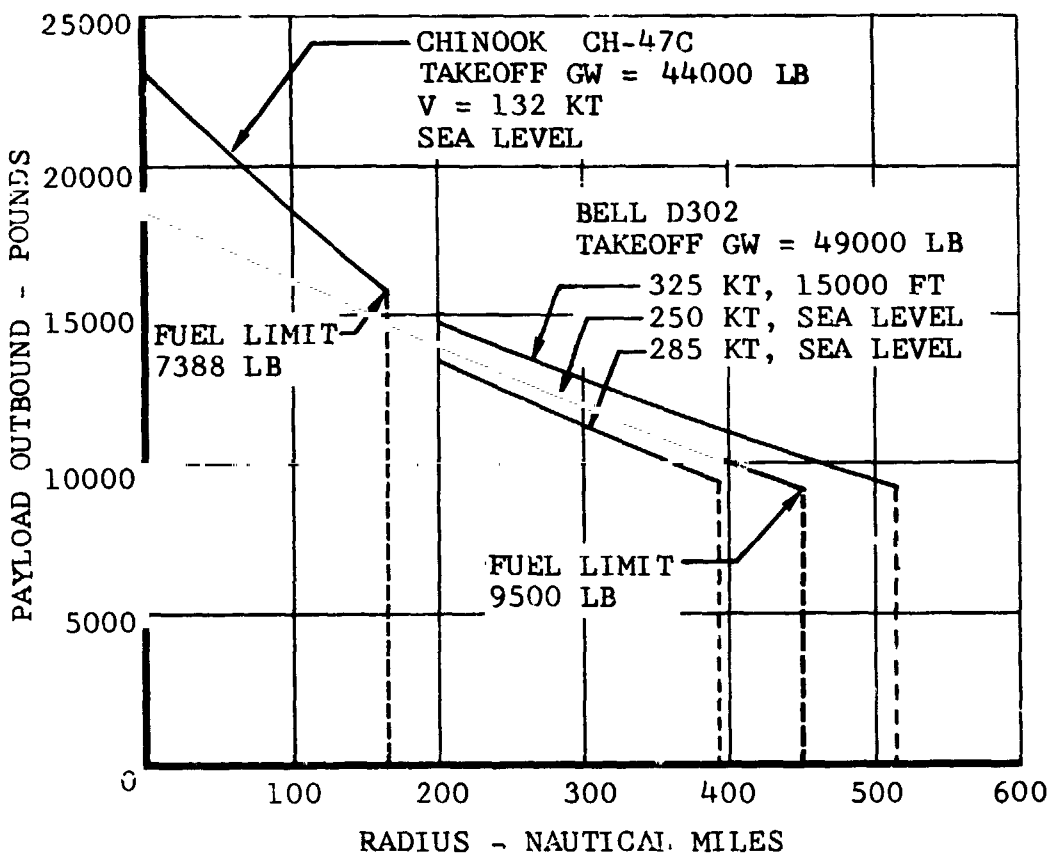


Figure IV-9. Comparison of the D302 Conceptual Aircraft with Chinook Helicopter, Payload-Radius.

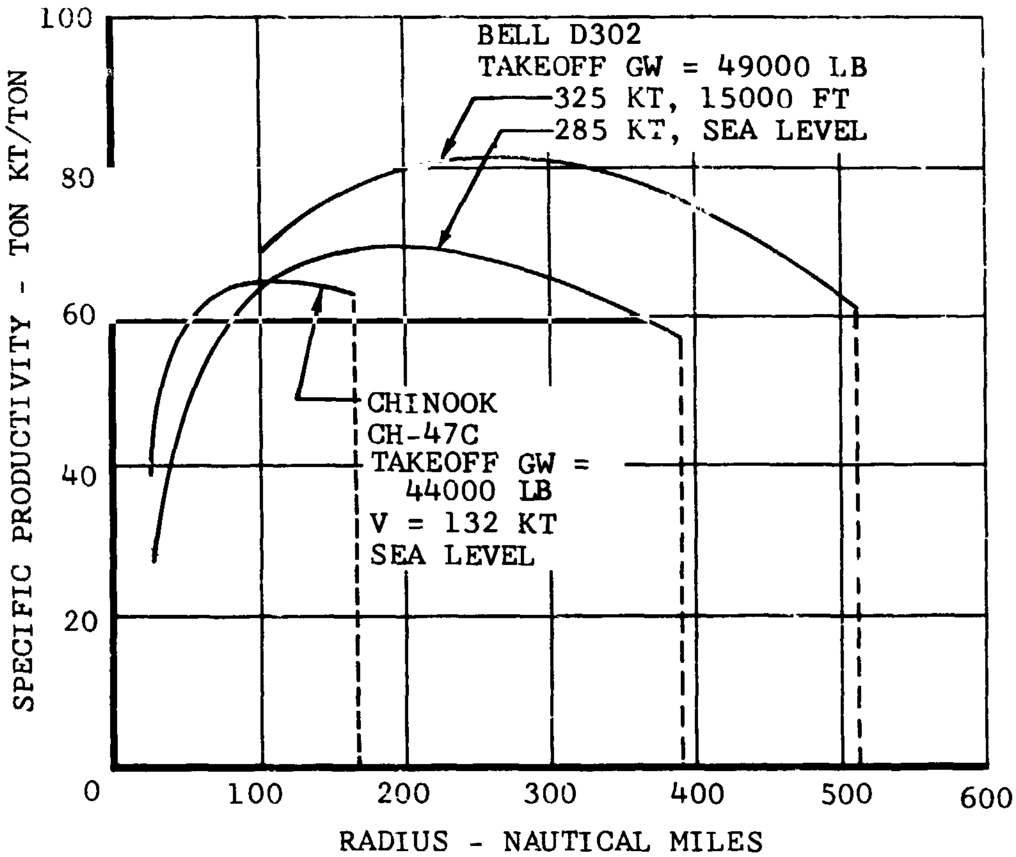


Figure IV-10. Comparison of the D302 Conceptual Aircraft and the Chinook Helicopter, Specific Productivity.

V. PERFORMANCE CHARACTERISTICS

A. RATE OF CLIMB

On a 95°F day, the D302 has a twin-engine rate of climb exceeding 2000 feet per minute at its FAA maximum gross weight (44,100 pounds). This climb is maintained to an altitude of 3000 feet as Figure V-1 shows. With one engine inoperative, a rate of climb of 200 feet per minute can be achieved at 60 knots (V_2) and an altitude of 1000 feet, using the engine's ten-minute rating. The latter conditions establish the maximum FAA gross weight. At 3000 feet altitude, in proprotor mode, the achievable climb gradient exceeds 1.25 percent at 200 knots EAS using maximum continuous power.

On a standard day, the twin-engine rate of climb exceeds 2500 feet per minute up to altitudes over 5000 feet, Figure V-2. With one engine operating at its ten-minute rating, a 200-foot per minute climb can be exceeded at weights up to 54,000 pounds. In proprotor mode, single engine rate of climb exceeds 250 feet per minute at weights up to 55,000 pounds.

B. HOVER CEILING

Hover ceilings were predicted with loss allowances for engine installation, accessories, and transmission gearing. On a hot day, total transmission rating of 8500 shp matches the twin engine ten-minute rating at 3800 feet. Hover in ground effect was assumed to require ten percent less power than hover out of ground effect.

On a hot day, the aircraft has ample out-of-ground-effect hover performance (Figure V-3); at 44,100 pounds, it hovers at 6100 feet. Single-engine hover in ground effect is possible at weights up to 42,600 pounds.

On a standard day, the twin-engine, out-of-ground-effect hover ceiling at FAA gross weight increases to 12,300 feet (Figure V-4), and single-engine, in-ground-effect hover is possible at an altitude of 600 feet using the engine's ten-minute rating. The emergency one-minute rating would provide additional margins. Maximum hover capability out of ground effect is 53,400 pounds at sea level.

C. SPECIFIC RANGE

Specific range is shown in Figure V-5 for a typical mid-range gross weight and a MIL Standard 210 hot day. Proprotor cruise tip speed is 600 feet per second, long-range cruise speed is 315 knots at 30,000 feet. This represents approximately seven percent less fuel flow, but ten percent longer time at cruise altitude than can be obtained with a 348-knot cruise speed. Figure V-6 shows specific range on a standard day and for a proprotor cruise tip speed of 520 feet per second. (Better propulsive efficiency is achieved on a standard day by reducing the cruise tip speed to 520 feet per second as described in Section II.) Best long-range cruise speed is 283 knots at 30,000 feet.

D. SPEED ENVELOPE

The twin-engine speed envelope extends from hover to 370 knots. The speed envelope in the airplane mode is shown in Figures V-7 and V-8. Typical cruise speed at 30,000 feet, with 95 percent of continuous power, is 348 knots on a hot day. A V_c of 300 knots at sea level provides structural strength for speeds beyond V_{max} capability at altitude.

On a standard day, the D302 standard proprotor, which is designed using current technology, incurs compressibility losses above 325 knots at 30,000 feet. For those conditions, a tip speed of 520 feet per second was found to provide improved speed capability compared to a tip speed of 600 feet per second.

The speed potential of advanced proprotors is shown in Figures V-8 and V-9. By thinning the airfoils by a section change of three-percent (e.g., a twelve-percent thick airfoil reduced to a nine percent thick airfoil), a speed increase to 375 knots was achieved. However, this change incurred a loss of hover lifting capability and an increase in blade structural weight. The productivity for the short-haul commercial mission actually reduced. Thus, it is felt that the standard proprotor is an optimum design. The proprotor blade airfoil thickness and twist distributions for the Task II research aircraft are identical to those of the D302. By the use of advanced airfoils to eliminate all compressibility losses, the D302 could achieve 390 knots, as shown. It is possible that advanced composite materials could make this a productive solution for longer-range VTOL missions.

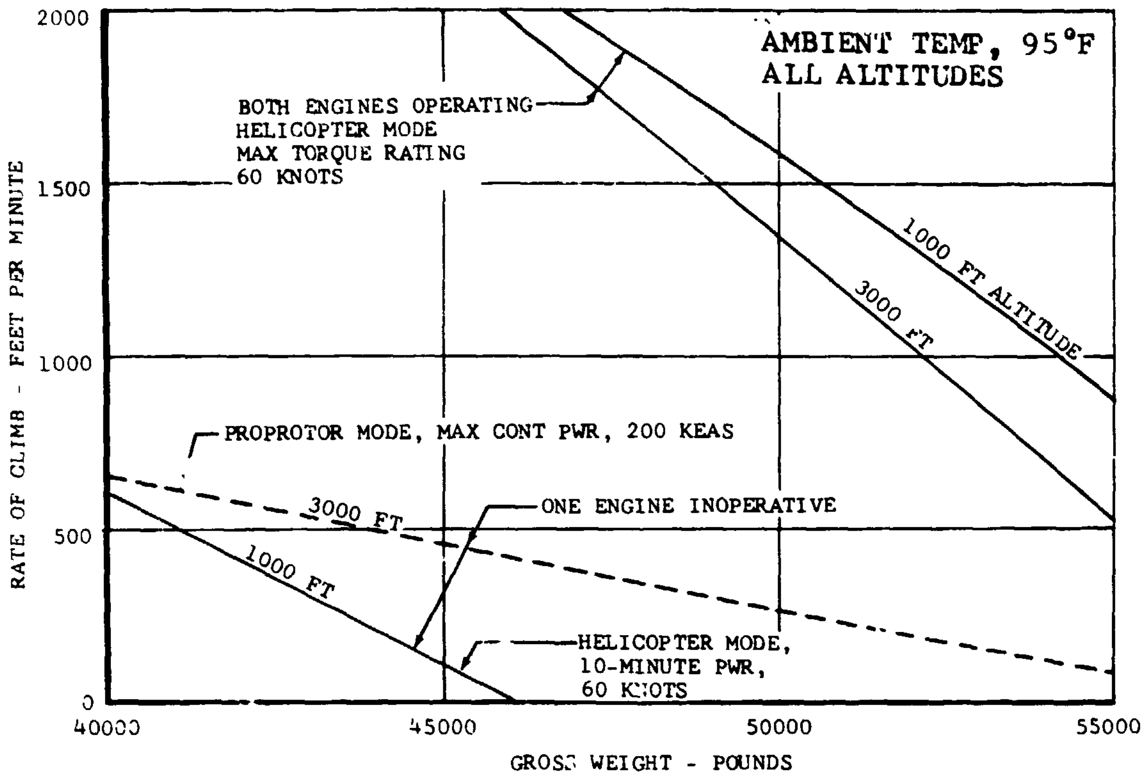


Figure V-1. 95°F Day, Climb Performance.

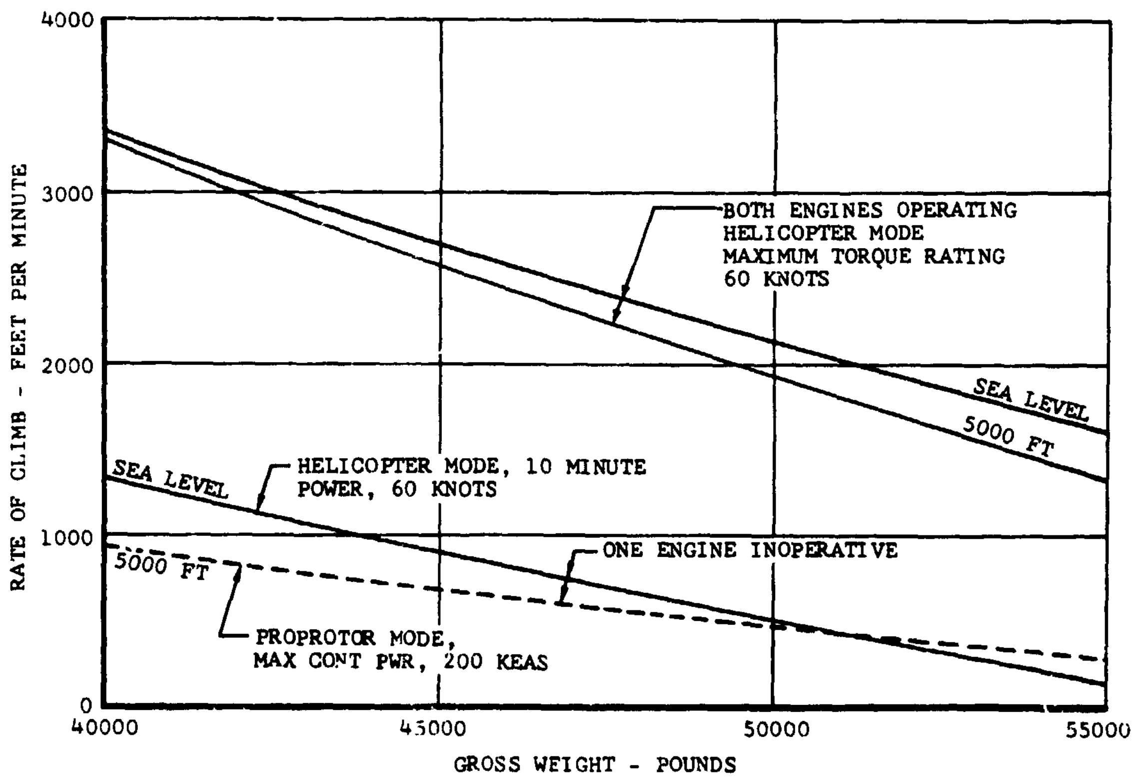


Figure V-2. Standard Day, Climb Performance.

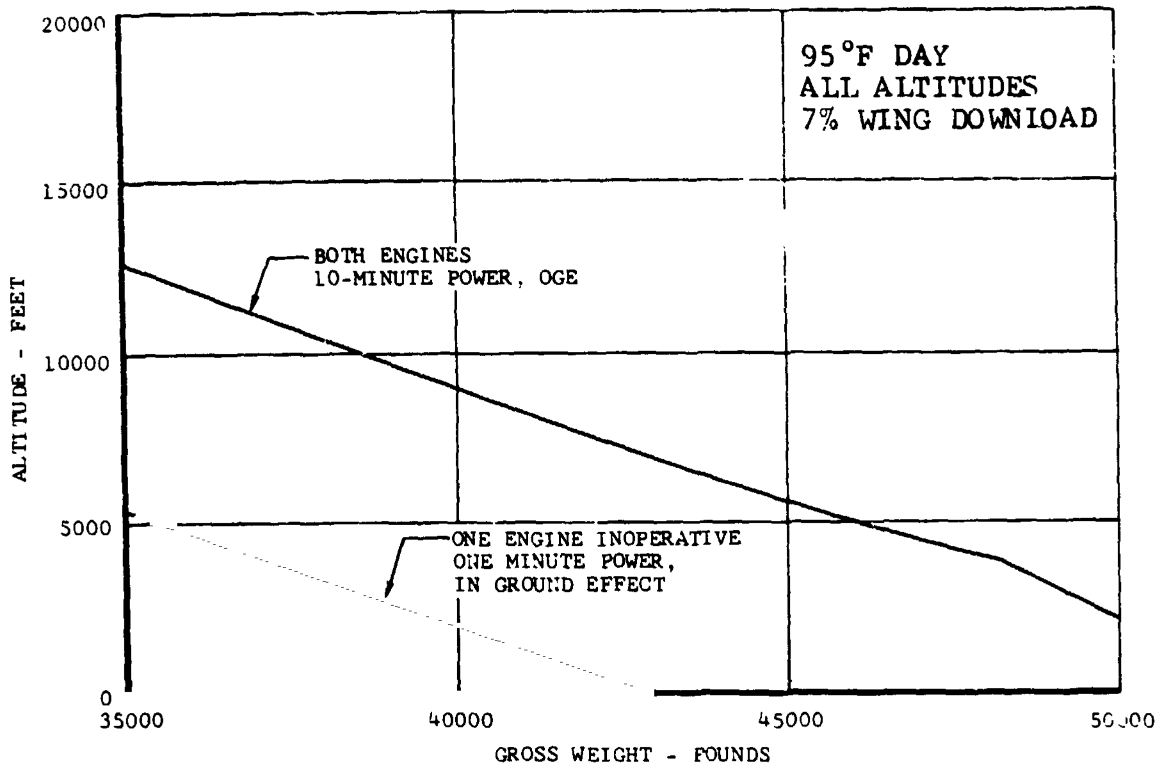


Figure V-3. 95°F Hot Day, Hovering Ceiling.

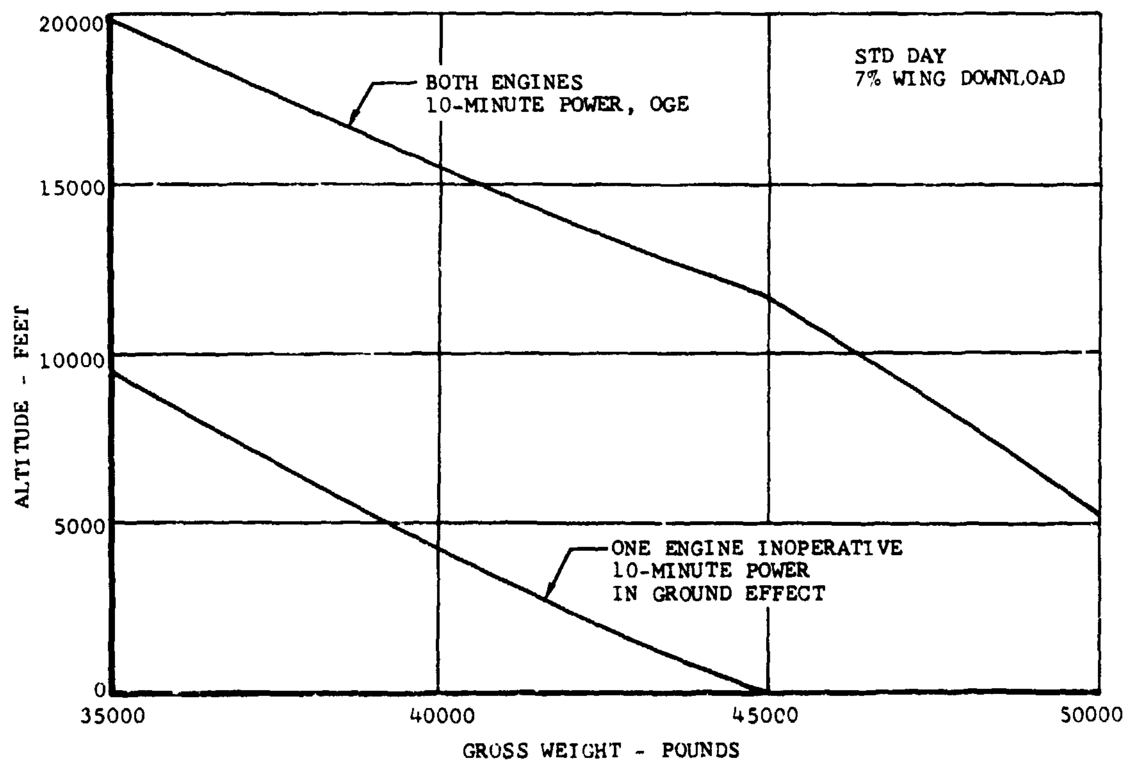


Figure V-4. Standard Day, Hovering Ceiling.

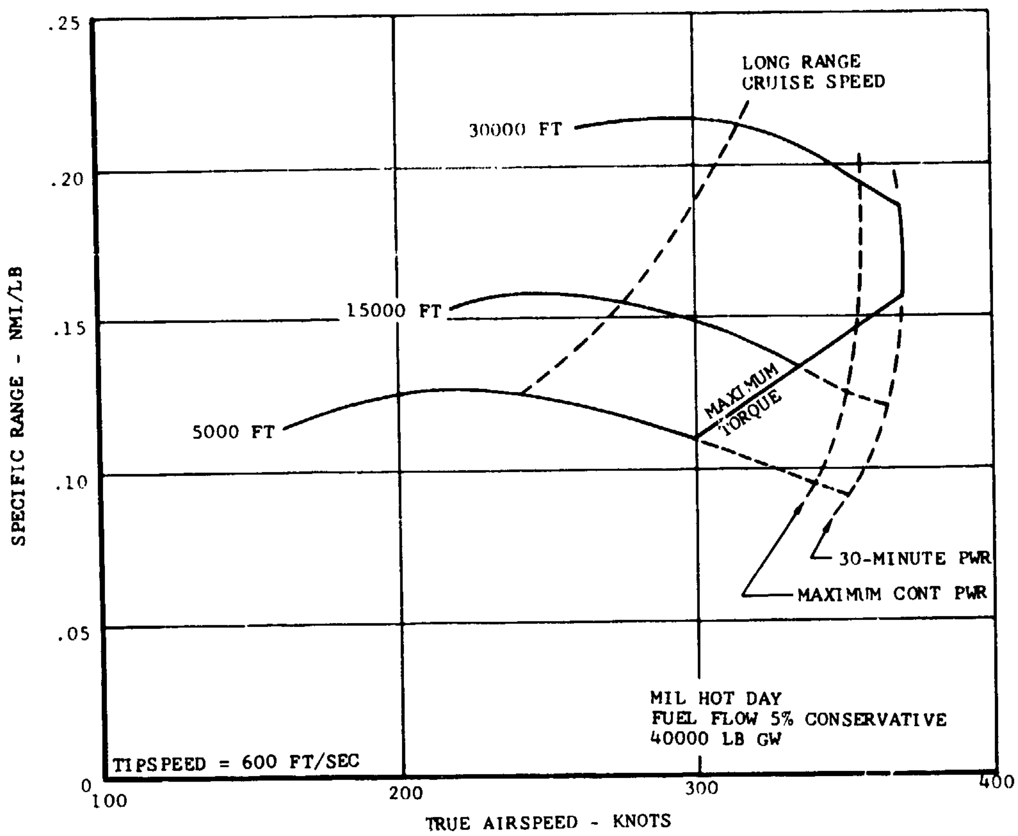


Figure V-5. Specific Range, MIL Standard Hot Day.

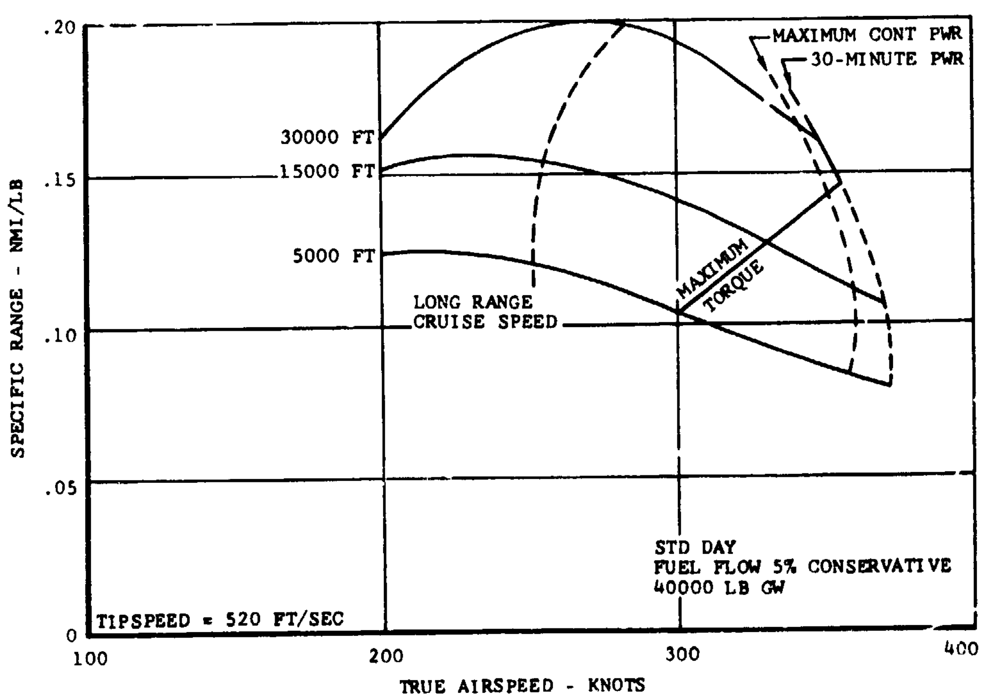


Figure V-6. Specific Range, Standard Day.

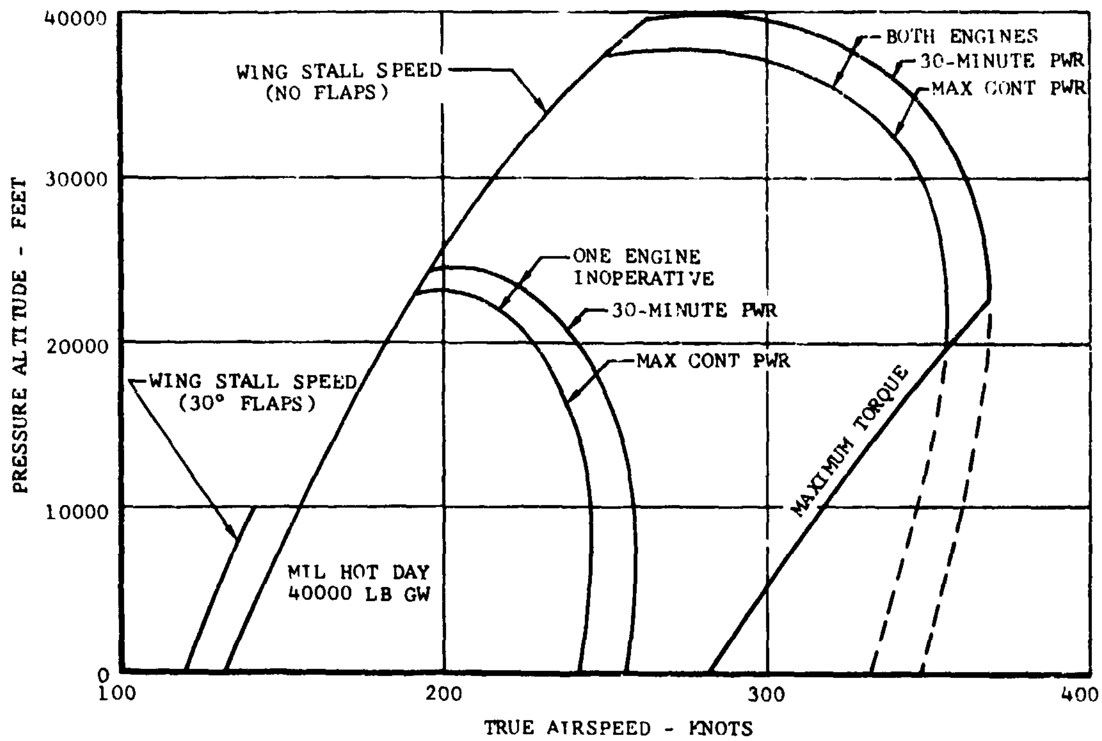


Figure V-7. Speed Envelope, MIL Standard Hot Day.

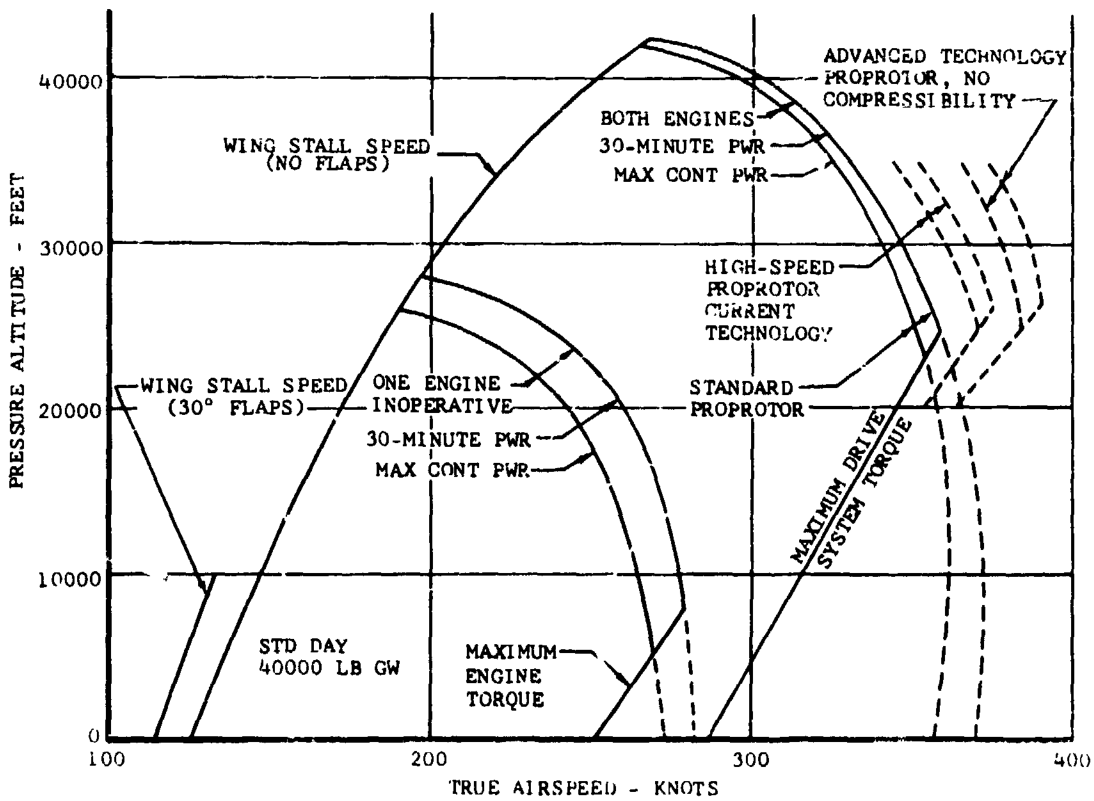


Figure V-8. Speed Envelope, Standard Day.

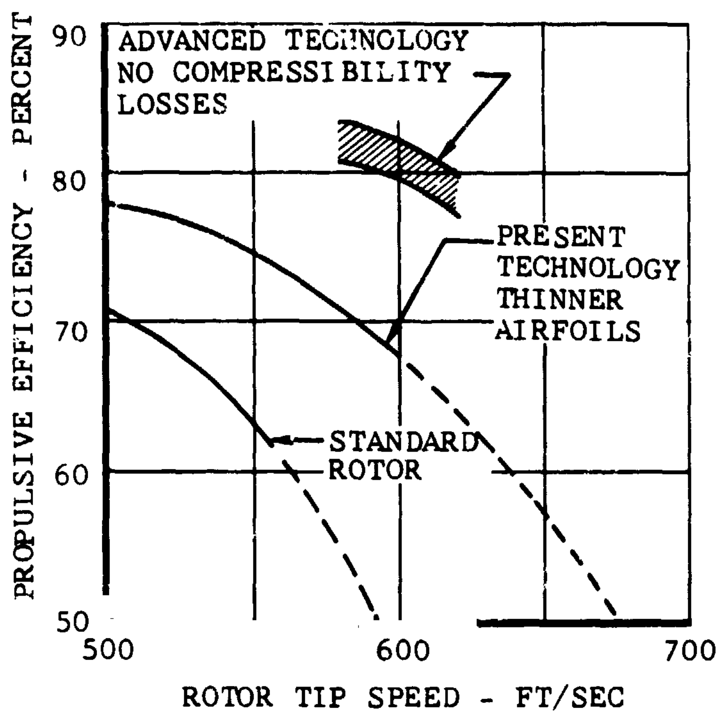


Figure V-9. Propulsive Efficiency of Advanced Proprotors at 350 Knots, 30,000 Feet, Standard Day.

VI. WEIGHT AND BALANCE

The component weights of the D302 conceptual design were estimated using parametric weight equations based on key design parameters for each of the major group weight items and are shown in Table VI-I. The weight estimating formulas were in use prior to the Army Composite Aircraft Program. Detailed component design and structural analyses during that effort afforded an opportunity to verify and improve estimating relationships, correlation constants, etc. Since that time, component design studies associated with the preliminary design of the Model 300 research aircraft, and those for various helicopter models, have provided further confidence in the techniques. These methods have been reported to the Government during the performance of work under Air Force Contract F33615-69-C-1578, Phase I and during Contract NAS2-5386. The technology represented assumes an improvement over current practice but is based on primarily aluminum, steel, and titanium adhesive-bonded structures. Use of advanced composite materials in selected components (e.g., empennage structures or wing box) should provide further gains. Engine weights are provided by the manufacturer. For the military transport version, the allowance for the extra weight of the cargo fuselage and rear ramp was 800 pounds. The allowance for modification of the cargo fuselage for the crane mission was 500 pounds. The empty weight for each mission considered is shown in Table VI-II. A logical next step in the design study of the D302 is the detailed design of selected components to refine the empty weight estimate.

A. USEFUL LOAD SUMMARY

Weight breakdowns for commercial and military mission takeoff weights are summarized in Table VI-II. The commercial short-haul mission is shown at a takeoff gross weight of 42,781 pounds which includes 40 passengers and 4375 pounds of fuel. This is sufficient fuel for one round trip, New York City to Washington, D.C. to New York City, based on 95°F takeoff conditions. The fuel capacity is 9500 pounds so that on a standard day takeoff there is the potential for making two round trips, New York-Washington-New York, without refueling.

B. CENTER-OF-GRAVITY RANGE

The center-of-gravity stations of the aircraft for the typical commercial mission are shown in Figure VI-1. The center-of-gravity shift due to pylon conversion from helicopter to airplane mode is shown. The center-of-gravity position in airplane mode is at 17.6 percent MAC at minimum flying weight and at 20.5 percent MAC at FAA maximum weight. Handling qualities for these loading conditions are analyzed in the Stability and Control Section.

TABLE VI-I. WEIGHT EMPTY SUMMARY

Group		Weight - lb
Rotor Group		46[illegible]
Wing Group		3196
Tail Group		1043
Body Group (Pressurized Fuselage)		4911
Alighting Gear		1433
Flight Controls		1694
Engine Section		392
Propulsion Group		7443
Power Plant Installation	2040	
Fuel System	808	
Drive System	4595	
Instrument Group		220
Hydraulic Group		285
Electrical Group		650
Avionics Group		1100
APU		175
Air Conditioning and Anti-Icing		978
Furnishing and Equipment		1840
WEIGHT EMPTY		29971

TABLE VI-II. USEFUL LOAD SUMMARY

	Commercial Short-Haul	Troop Transport	Military Rescue	Military Cargo	Military Crane	Ferry
Weight Empty	29971	29971	29971	30771	31271	29971
Pilot, Copilot	380	380	380	380	380	380
Flight Attendant	135	-	570	190	190	-
Fluids	320	320	320	320	320	320
Operating Weight	30806	30671	31241	31661	32161	30671
Payload	7600	11520	3000	10000	20000	-
Fuel, Internal	4375*	9500	9500	9500	1239	9500
Fuel, External Auxiliary	-	-	5500	-	-	-
Fuel System, External	-	-	500	-	-	-
Fuel, Internal Auxiliary	-	-	-	-	-	12250
Fuel System, Internal	-	-	-	-	-	979
Gross Weight	42781	51691	49741	51161	53400	53400

*Typical for one round-trip with reserves.

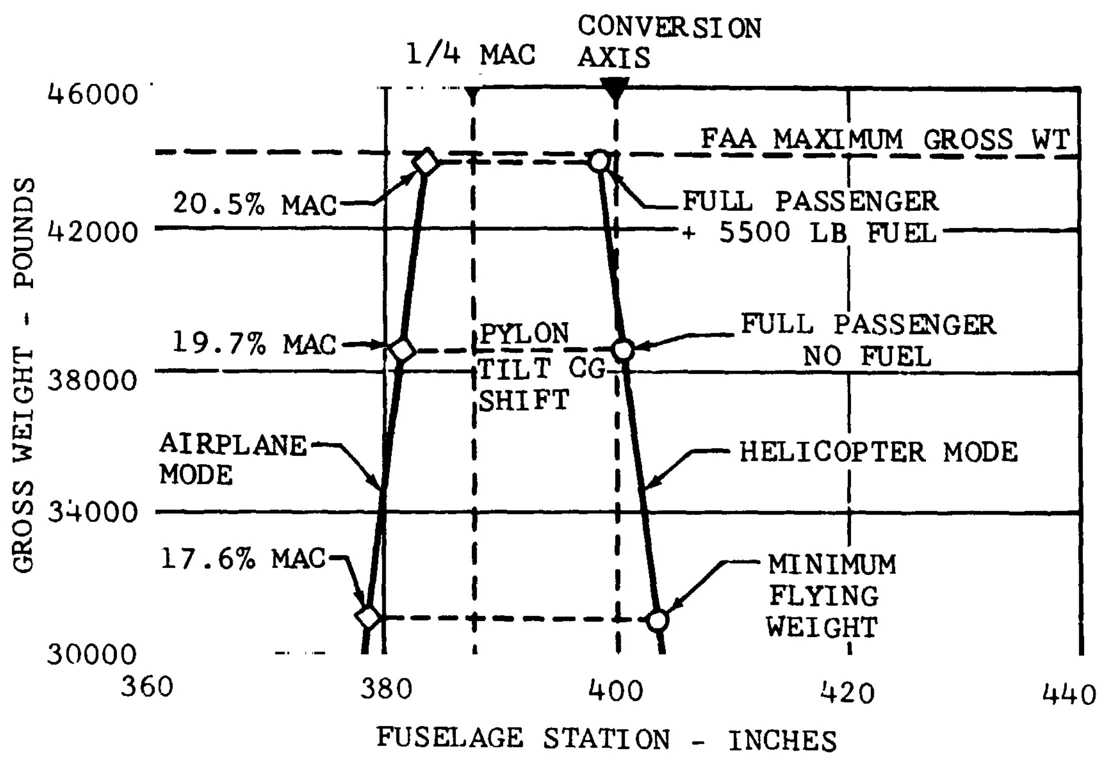


Figure VI-1. Loading Conditions, Commercial Mission.

VII. STABILITY AND CONTROL

A. TAKEOFF MODE (HELICOPTER)

Aircraft center-of-gravity limits for a proprotor aircraft are established by the control margin requirements in the takeoff or helicopter mode. A preliminary analysis of longitudinal control in the low-speed range, representative of takeoff operations, has been completed. The allowable center-of-gravity envelope is shown in Figure VII-1. This center-of-gravity envelope is based on a rotor flapping range of 6 degrees aft to 2 degrees forward. In addition to the rotor thrust vector displacement with flapping, there is an additional hub moment applied through the hub spring which is equivalent to an added one inch center-of-gravity travel per degree of flapping. The aft limit of the center-of-gravity envelope is based on maintaining an adequate forward control margin at 100 knots with a mast angle of 75 degrees. The forward limit of the center-of-gravity envelope is based on maintaining an adequate aft control margin in rearward flight at 35 knots with a mast angle of 90 degrees.

Figure VII-2 shows stick position versus airspeed for a range of conversion angles with the aircraft center of gravity at fuselage station of the conversion axis, Station 400. The probable range of fuselage attitudes that will be used varies from level to plus 10 degrees, and is indicated in the figure.

B. CRUISE MODE (AIRPLANE)

Dynamic stability in airplane flight was analyzed to determine the longitudinal short period and Dutch roll characteristics for altitudes of sea level to 40,000 feet and airspeeds of 150 to 350 knots.

Figure VII-3 compares the short period frequency characteristics with criteria in MIL-F-8785. It is seen that the D302 is well within the requirements for Level 1. Figure VII-4 compares the Dutch roll frequency and damping characteristics with criteria in MIL-F-8785. The D302 meets the Level 1 requirements for all practical airspeeds up to the cruise altitude of 30,000 feet. At low airspeeds and higher altitudes, the Dutch roll characteristics deteriorate to Level 2. While the stability and control augmentation system will alleviate this, it is not a critical situation since flight is not normally conducted at those combinations of airspeed and attitude.

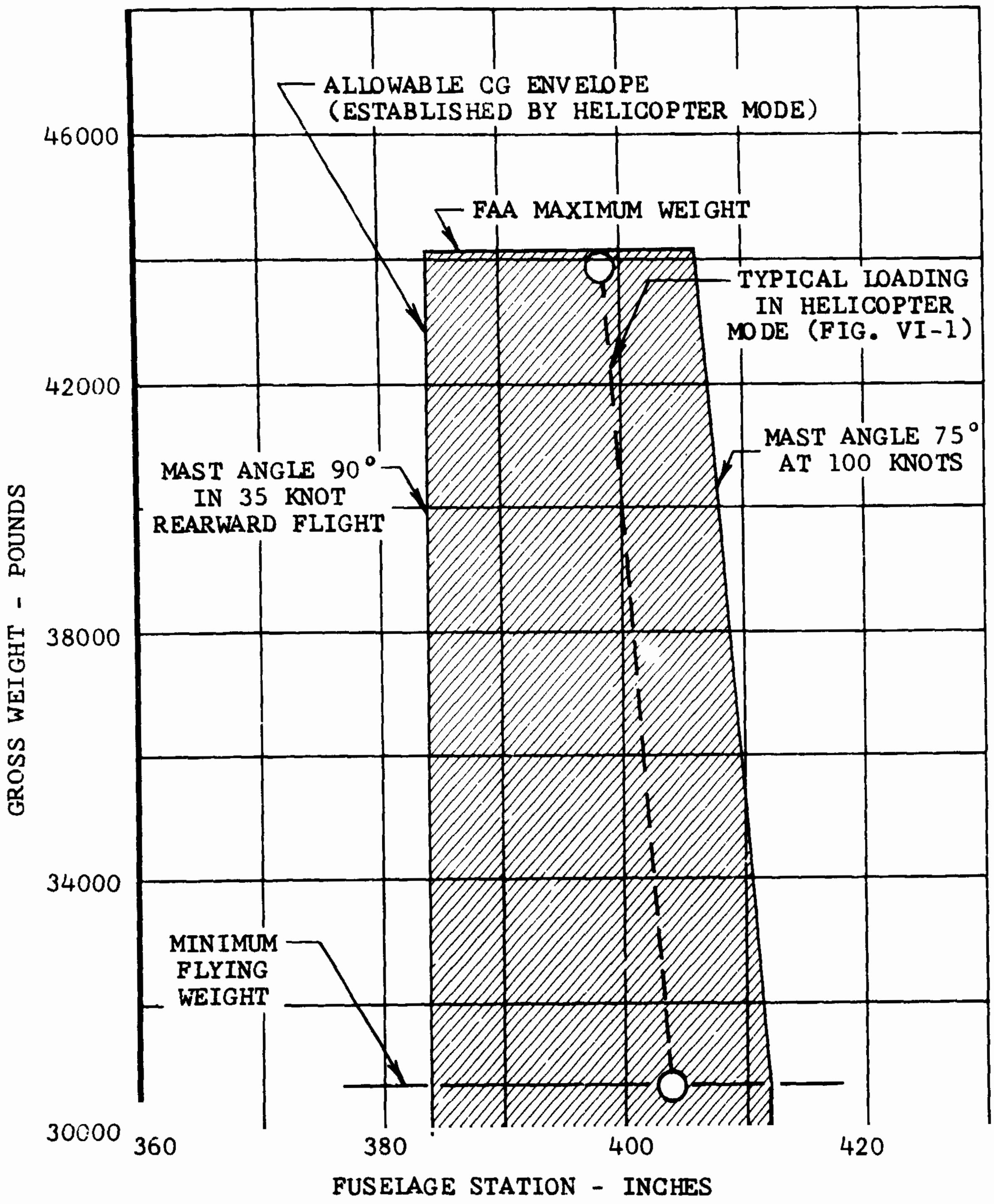


Figure VII-1. D302 Conceptual Aircraft Allowable Center-of-Gravity Envelope.

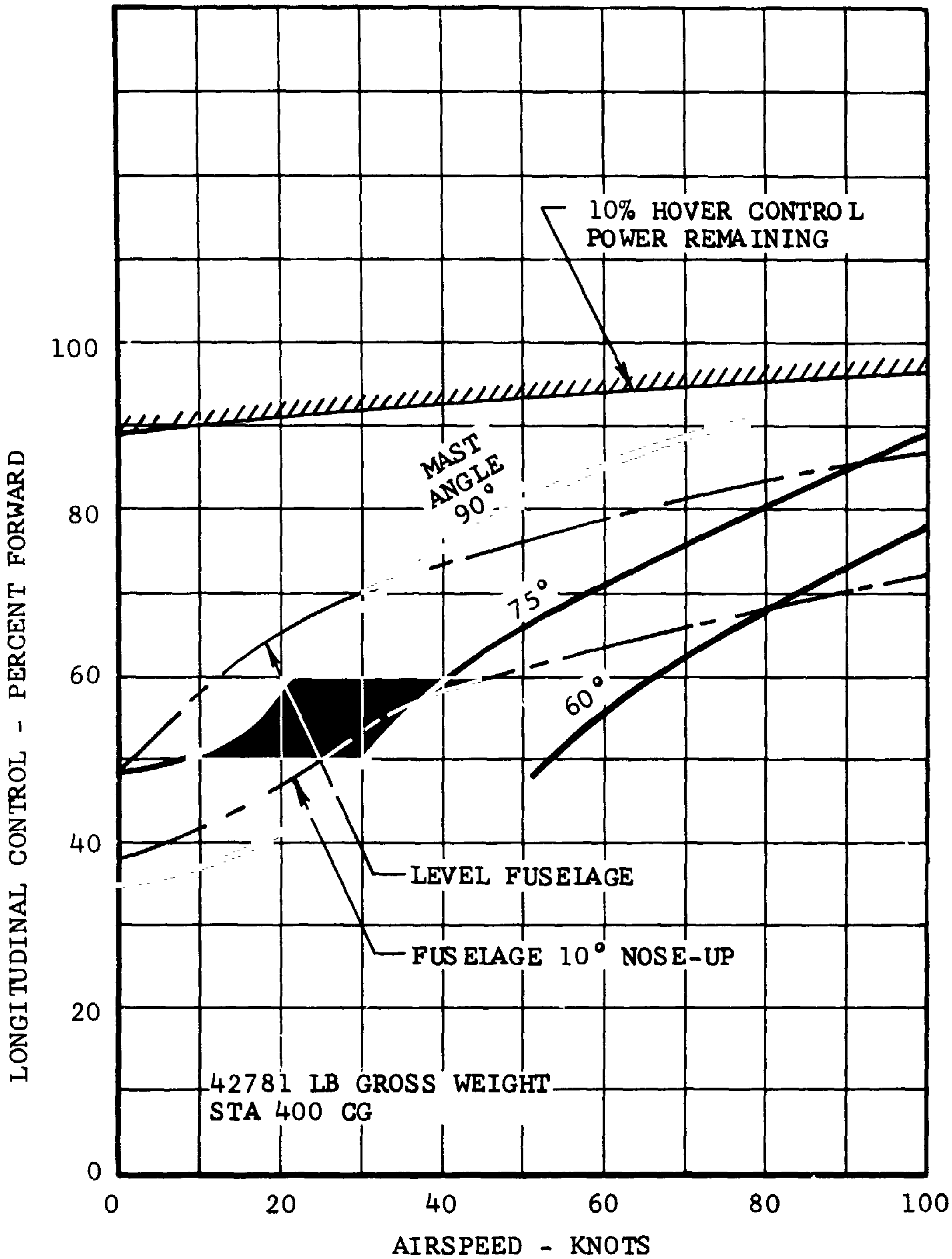


Figure VII-2. D302 Conceptual Aircraft Longitudinal Control in Helicopter Mode.

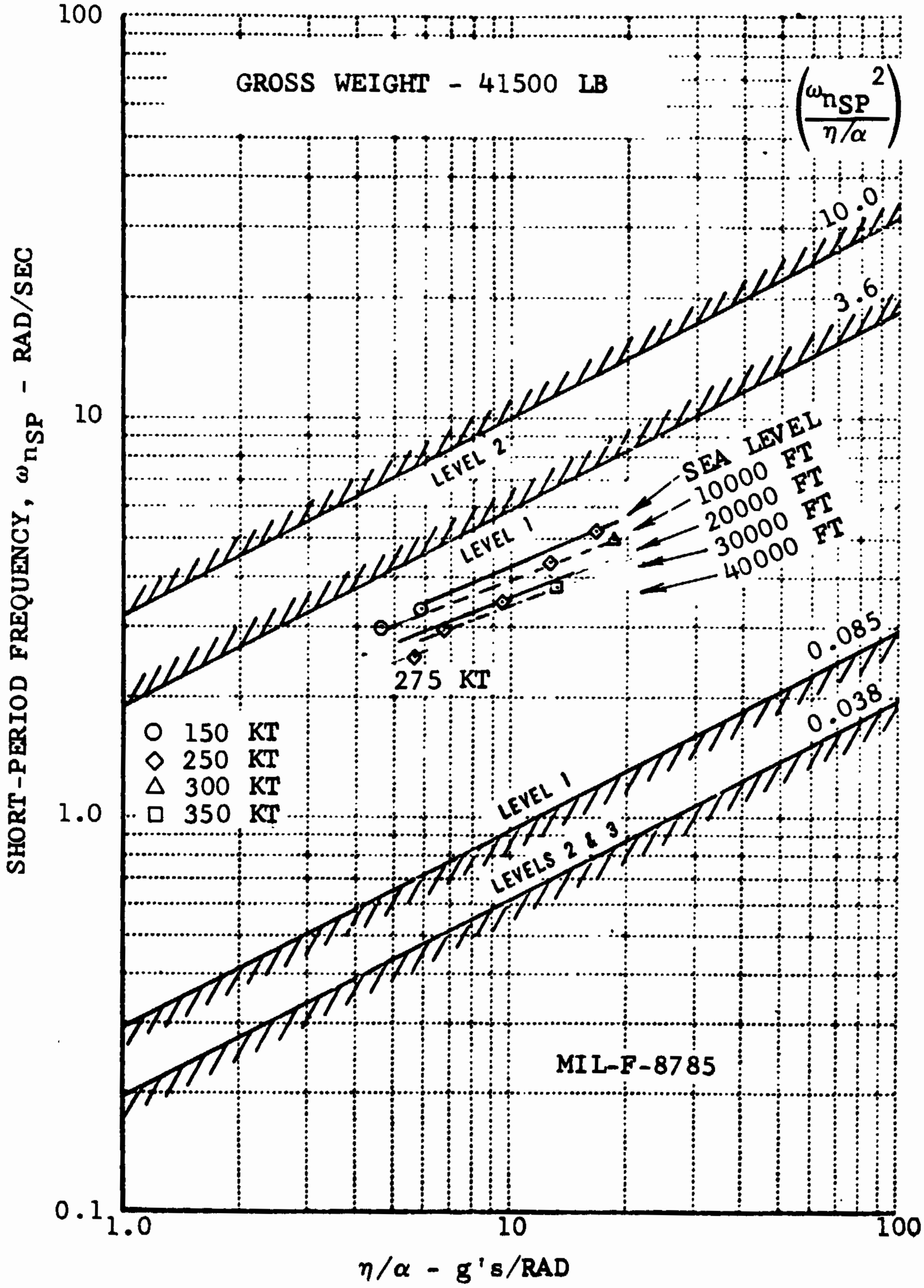


Figure VII-3. D302 Conceptual Aircraft Longitudinal Short-Period Characteristics.

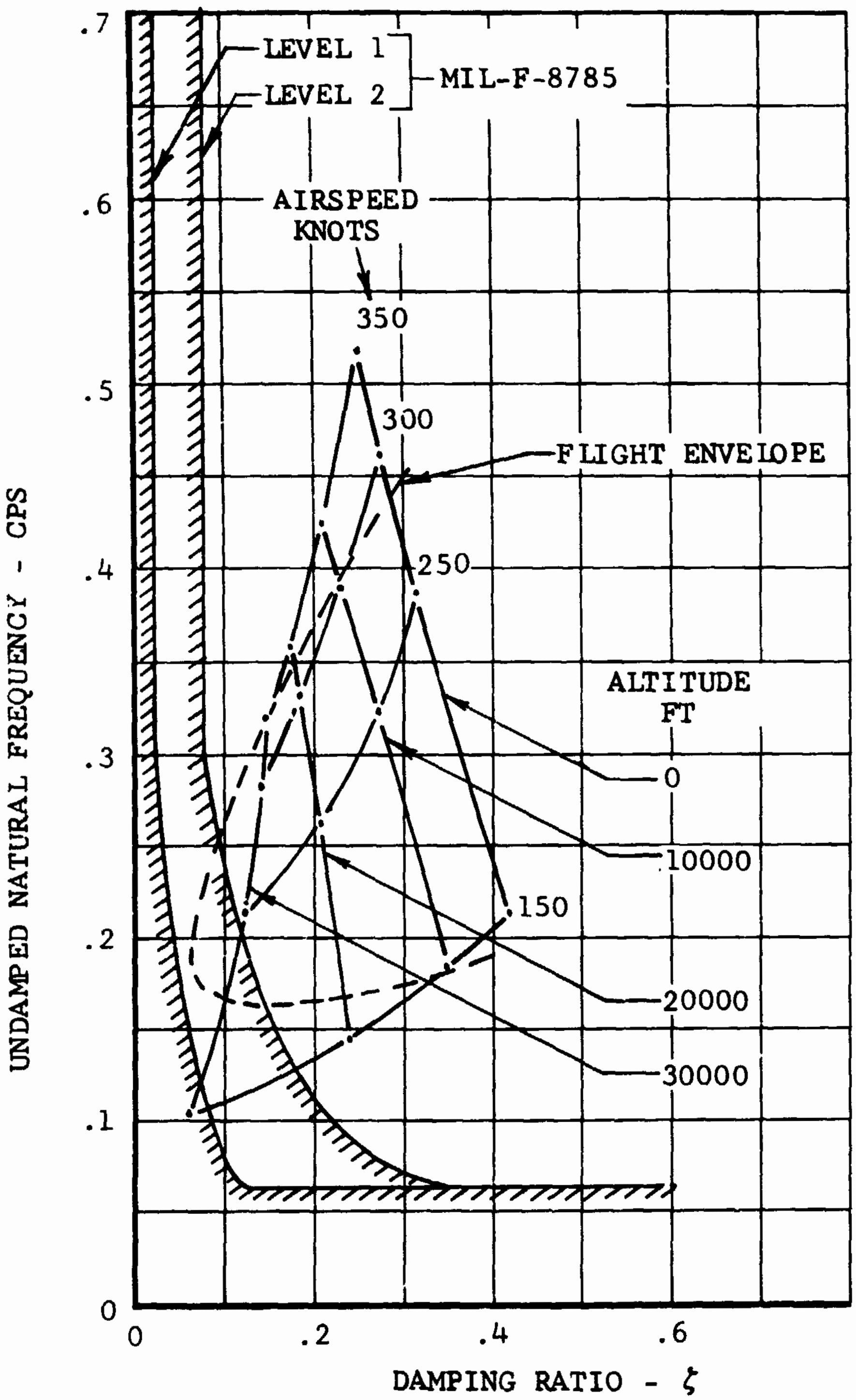


Figure VII-4. D302 Conceptual Aircraft Lateral-Directional Characteristics in Airplane Mode.

VIII. DYNAMIC CHARACTERISTICS

A. PROPROTOR

Basic blade structural properties were determined to meet preliminary loads criteria. Mass and stiffness distribution were then estimated and proprotor natural frequencies calculated. The proprotor collective and cyclic mode natural frequencies are shown in Figures VIII-1 and VIII-2, respectively.

The D302 blade design will be satisfactory from an oscillatory loading standpoint since the major exciting frequencies (one-per-rev for cyclic modes and three-per-rev for collective modes) are well removed from the blade natural frequencies.

B. AIRCRAFT

The dynamic stability of the aircraft was analyzed in the airplane mode of flight. The analysis included the forward and backward blade flapping, forward and backward blade inplane bending, wing beam bending, wing chord bending, wing torsion, and pylon yaw modes. Damping and frequency were then calculated for the symmetric and asymmetric modes. The D302's aeroelastic stability boundaries are shown on Figures VIII-3 and VIII-4 as a function of rpm and altitude. The boundaries are for the symmetric wing chord mode, which is the first mode to go unstable as airspeed is increased.

Figure VIII-3 shows that at the cruise rpm of 207, the stability boundary is over 400 knots at sea level. Figure VIII-4 shows that the stability increases with altitude. The aircraft's flight envelope and the FAA's flutter-free speed of 1.20 x 1.15 x V_{max} is also shown on Figure VIII-4. It is seen that the stability boundary is greater than the required flutter-free speed for all altitudes.

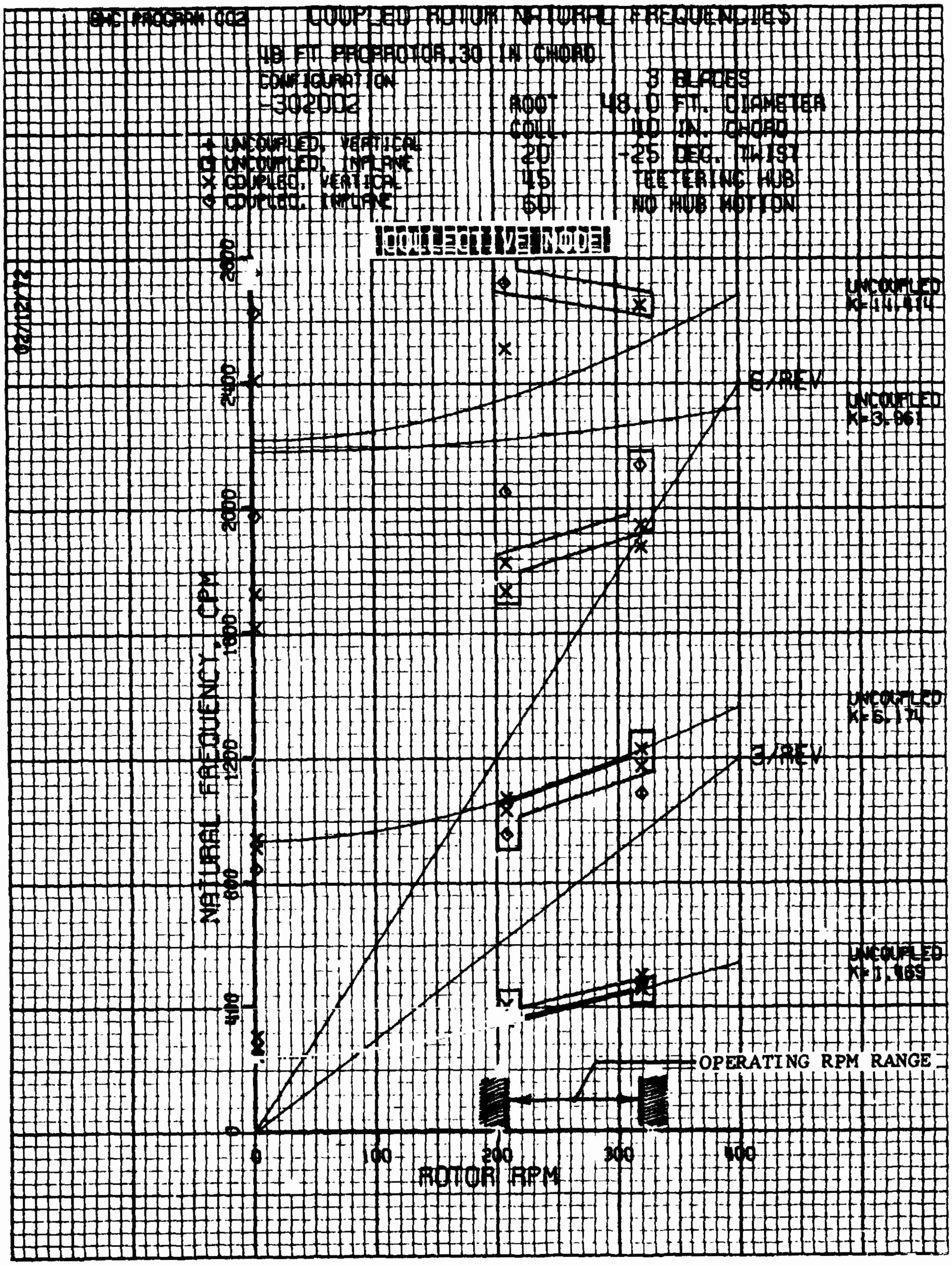


Figure VIII-1. Natural Frequencies, Collective Mode.

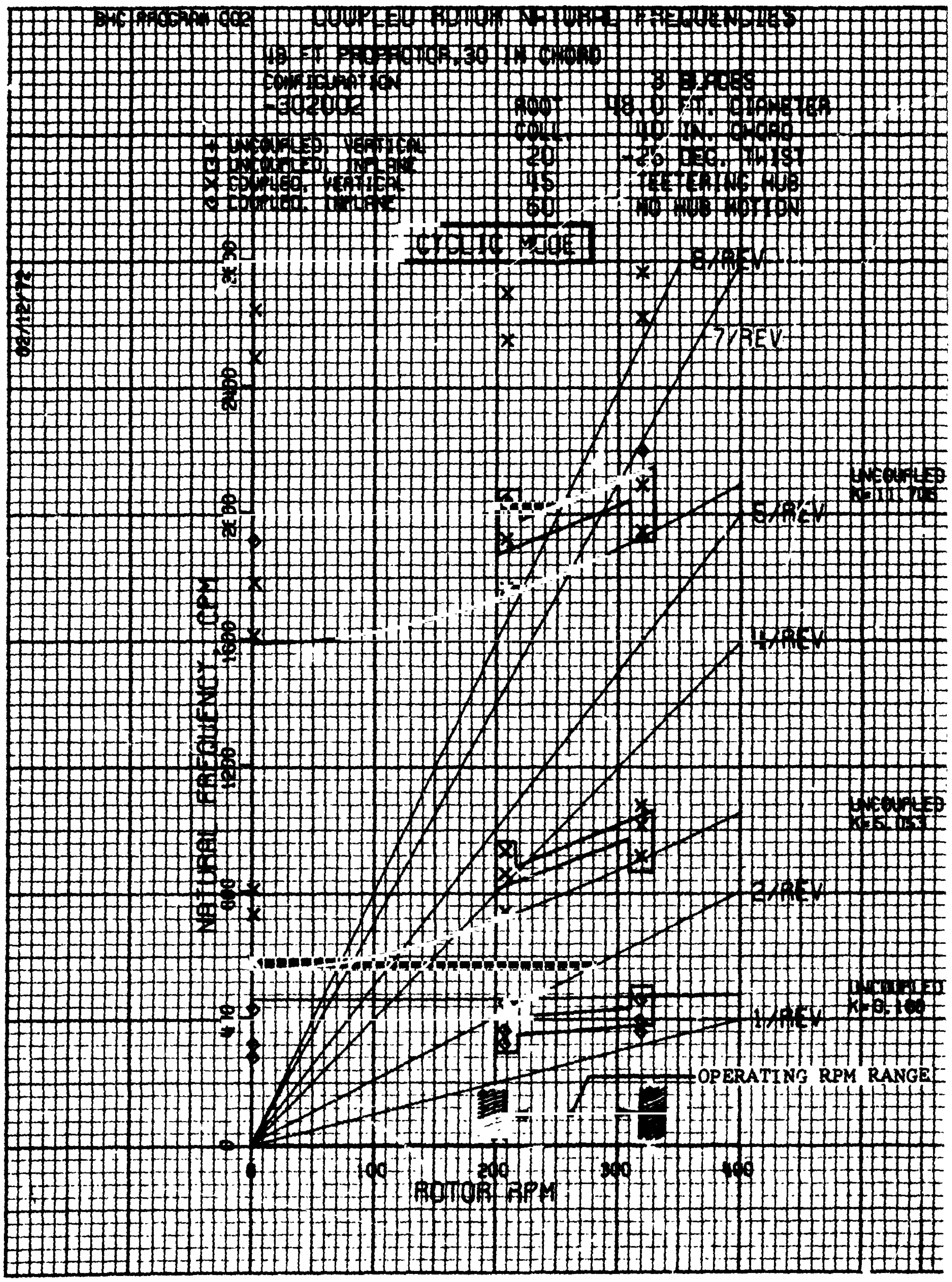


Figure VIII-2. Natural Frequencies, Cyclic Mode.

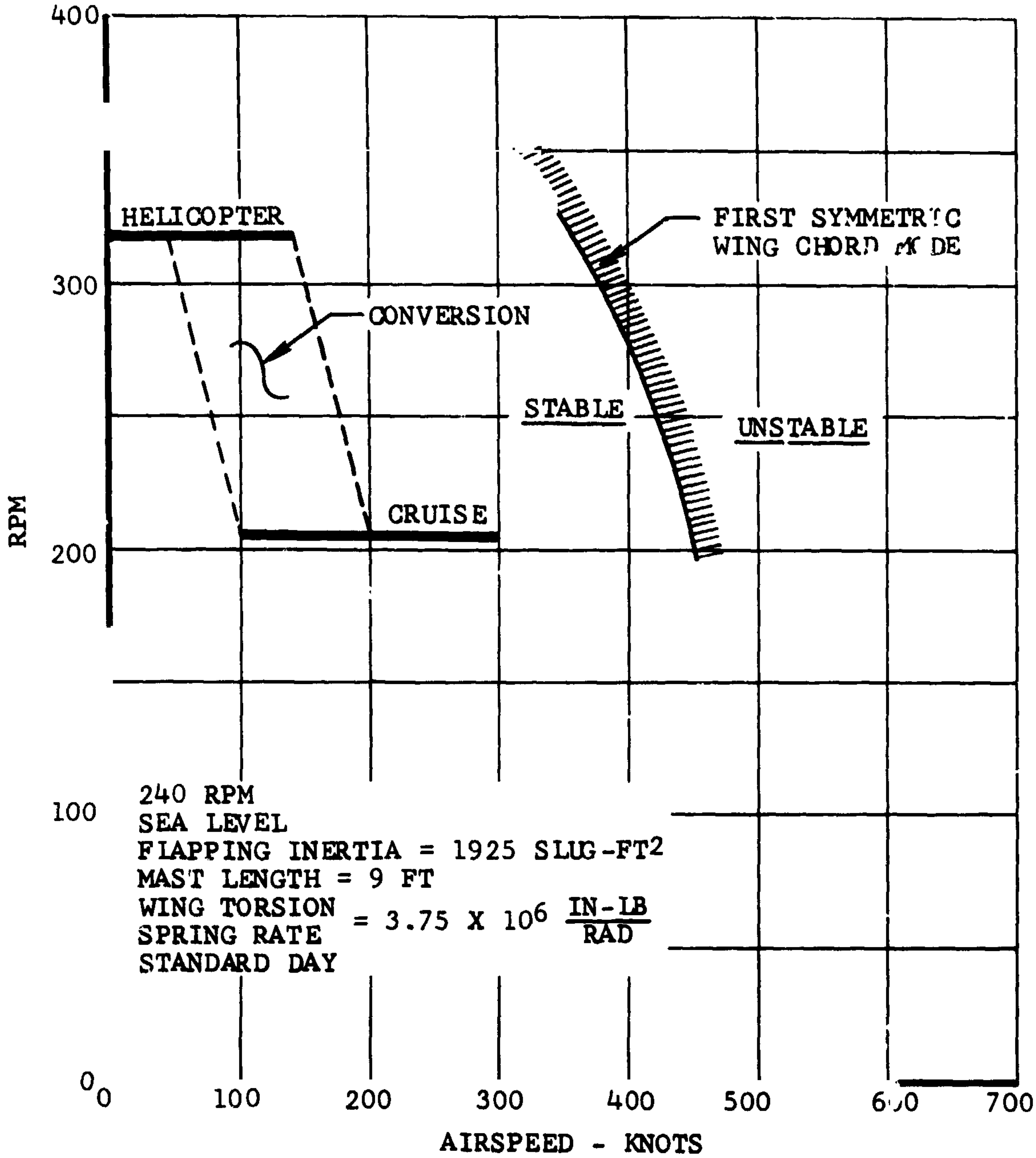


Figure VIII-3. D302 Conceptual Aircraft Dynamic Stability Boundary Versus RPM, Airplane Mode.

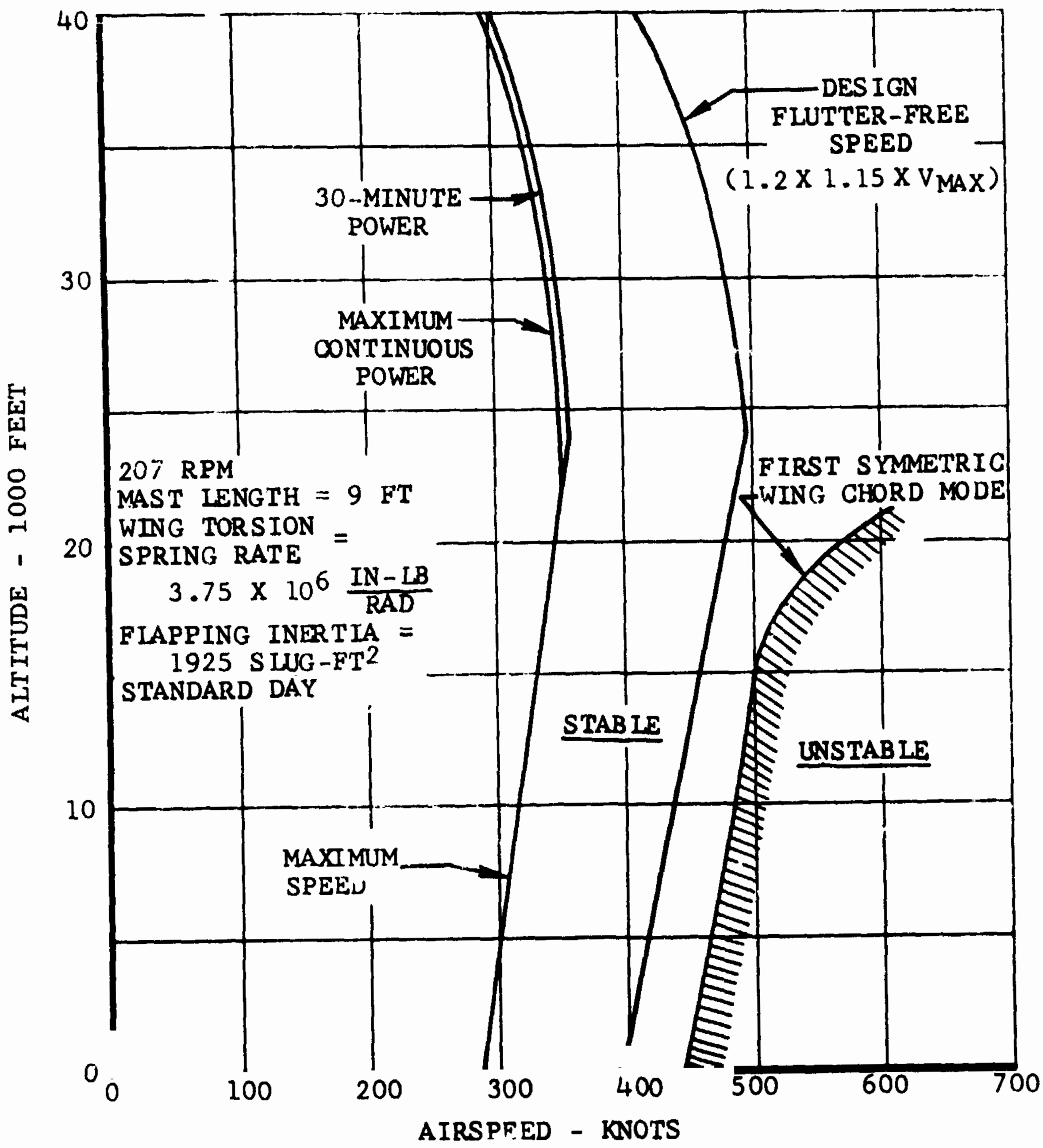


Figure VIII-4. D302 Conceptual Aircraft Dynamic Stability Boundary Versus Altitude, Airplane Mode.

IX. RELIABILITY AND MAINTAINABILITY

A. RELIABILITY

The tilt-proprotor aircraft combines rotary-wing and fixed-wing aircraft components and operates in both the rotary-wing and fixed-wing flight regimes. The structural load spectrum for the proprotors in cruise mode (axial inflow) is predicted to be considerably better than for typical helicopters in their cruise mode (edgewise inflow, with high oscillatory blade loads). The proprotors will be exposed to helicopter-type moderate oscillatory loads during pylon conversion for approximately ten seconds per conversion at 60-80 knots. However, proprotor aircraft need not fly for prolonged periods at the higher oscillatory loads such as would be experienced with pylons near vertical at 120-140 knots. These features should allow an increase in the main rotor Time-Between-Overhaul (TBO) from the typical 1000-1200 hours for the UH-1 helicopter. In military operation, for typical VTOL transport missions, a reasonable proprotor TBO target would be 5000 hours. In commercial airline service, operating from concrete pads and in cleaner air, an achievable proprotor TBO target should be 10,000 hours.

B. MAINTAINABILITY

The maintenance requirements of fixed-wing and rotary-wing aircraft, based on operating experience are shown in Figure IX-1. The data source for the military aircraft was USAAMRDL Technical Report 71-18A and for the commercial aircraft Naval Air Systems Command Report 3032-71-02. The maintenance requirements of tilt-proprotor aircraft in military operations are predicted to fit in the band between military helicopters and military fixed-wing transports.

Also shown is the maintenance estimate for the Bell D302 in commercial short-haul VTOL operations. This was based on Bell experience with commercial helicopters for the rotary-wing components and on airline operating experience for the fixed-wing items. The maintenance and overhaul requirement for the D302 (empty weight 29,971 pounds) is estimated to be 7.34 maintenance manhours per flight hour. It is estimated that a fixed-wing jet-transport of twice the gross weight would have approximately the same maintenance requirements per flight hour. These data were used in the operational economic analysis presented in the civil transport section of this report.

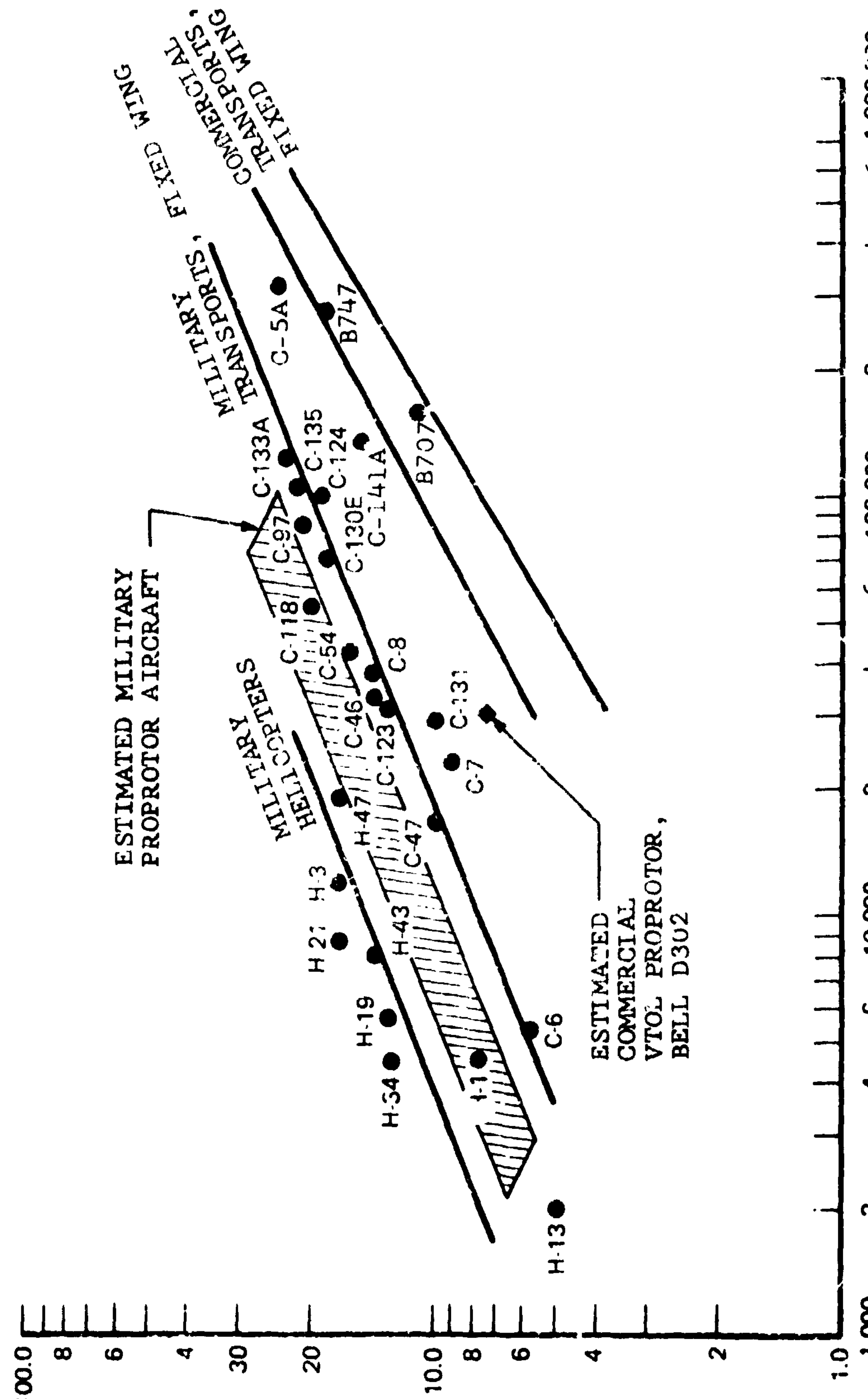


Figure IX-1. Maintenance Requirements, Fixed Wing and Rotary-Wing Aircraft.

X. ASSESSMENT OF NEEDED RESEARCH

The existing technology base for the tilt-proprotor aircraft configuration has provided low-risk, simple solutions for the aeroelastic stability problems identified by tests of the XV-3. The remaining areas of research are in the category of providing an extended technical data base from which can be drawn the means to optimize new designs for specific missions. Generally, these data will fall in the category of performance, stability and control, dynamics, and noise qualities as a function of specific design parameters. How far the designer can go in the direction of selecting better parameters will depend on weight trade-offs which can be alleviated by continuing design efforts based on advanced structural methods for specific components. Some of the areas in question depend on operational experience which can be provided only by flight research.

Specifically, some research areas identified in the conceptual design effort and for which the research aircraft can provide valuable data are:

- Low speed, takeoff mode, and descent aerodynamics involving better definition of the performance and stability and control characteristics of the tilt-rotor aircraft require test and verification.

- Aeroelastic stability and component load prediction and design techniques for the tilt-proprotor appear to be in hand, but flight verification is needed.

- Ride quality assessment, which was beyond the scope of the Task I effort for the D302, is the next area of attention for VTOL dynamics research. Ride quality assessment in terms of human subjective response which cannot be scaled is an important area for research to ensure acceptable operational aircraft.

- Noise alleviation techniques based on analytical investigations and potential operational procedures can only be verified by flight research.

Flight tests of the XV-3 pointed out that there was more to be learned through the lower speed modes of flight (vertical, takeoff, low speed, conversion) especially in the areas of porprotor downwash impingement on the airframe and its subsequent effect on performance, stability, handling, trim, and vibration. Analytical, model, and full-scale tests are possible approaches to obtaining the desired data. Analytical methods rely heavily on previously-determined empirical data, and model investigations can continue to have valuable inputs to the analytical work--and simulator studies. They can also have valuable inputs to the full-scale design effort. Powered aerodynamic and aeroelastic model tests for example can provide data and technical insight that are not readily obtainable, or in certain cases, not obtainable at all, from flight tests of a complete aircraft. A model program can isolate the dynamic coupling and aerodynamic interference effects of the various components of the aircraft by testing individual components as well as the complete aircraft. Semi-freeflight aeroelastic model testing can provide a more realistic and closer simulation of the full-scale aircraft's flight behavior than testing of the actual aircraft in full-scale wind tunnels (that are available today). However, each has its place and can provide valuable information.

The usefulness of the D302 is highly dependent on its achieving the predicted payloads, speeds, VTOL capabilities, and cost when placed in service. Its design and manufacture should benefit greatly from prior experiences with a smaller, less costly flight-research aircraft provided the research aircraft is designed as a productive aircraft in its own weight and size class. The flight investigations which the research aircraft can perform are discussed in detail in Section II, Volume I (Task II) of this study. In general, the objectives are to (1) establish the viability of the concept to perform military and commercial missions, (2) establish a technology base for the confident design of such aircraft, and (3) provide the potential user, regulating agency, and the community and military planner with the factual information required for the introduction of such aircraft into transportation systems.

NASA can accomplish these objectives in a research aircraft program. Flight research would evaluate proprotor/pylon dynamic stability, short-period aircraft stability, low-speed handling characteristics in and out of ground effect, proprotor propulsive efficiency, proprotor flapping in gusts and maneuvers, steep descent and approach capability, gust sensitivity and riding qualities, downwash and ingestion, noise, and pollution.

Potential of the concept should be extendable to even larger aircraft than the D302 through an orderly progression of research, development, and operational experience. Basically, the configuration can remain unchanged but advantage can be taken of size effects on weight, drag, and propulsion system efficiencies. These are in addition to advantages which may be expected as a result of advanced materials. Continued research in the design and testing of large-scale rotors would appear desirable.