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HELICOPTER PAYLOAD GAINS UTILIZING WATER INJECTION FOR HOT DAY POWER AUGMENTATION

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SUMMARY

An analytical investigation was undertaken to assess the gains in helicopter mission payload through the use of water injection to produce power augmentation in an altitude-hot day environment. Substantial gains are shown for two representative helicopters, the UH-1H and CH-47B. The UH-1H payload increased 86.7% for a 50 n.mi. (92.6 km) radius mission involving two out-of-ground effect (OGE) hover take-offs of 2 minutes each at 5000 ft. (1525 m) 35°C ambient conditions. The CH-47B payload increased 49.5% for a 50 n.mi.(92.6 km) radius mission with sling loaded cargo as the outbound payload and a 3000 lb. (1360 kg) internal cargo on the return leg. The mission included two 4 min. OGE hovers at 6000 ft. (1830 m) 35°C.

An improvement in take off performance and maximum performance climb also resulted as a consequence of the OGE hover capability and higher maximum power available.

INTRODUCTION

Present day turbine powered helicopters may lose substantial hover performance when the ambient temperature rises. For example, the UH-1H helicopter loses 1500 lb (680 kg) hover gross weight capability as the temperature rises from 15°C to 35°C at 5000 ft. (1525 m) altitude. This decrement in gross weight and hence useful load in largely the result of engine power drop-off with temperature. Some of the lost power and useful load can be recovered by injecting water into the engine compressor inlet. Water injected into the compressor inlet increases power by evaporative cooling of the inlet air, with a consequent increase in compressor pressure ratio and mass flow and an attendant increase in power. Useful load is recovered by restricting the water utilization time to short periods.

Water injection has been used in the past by airline operators of 707 and DC-8 aircraft with the J-57 engine. Presently the 747, with the JT9D engine, uses water injection for take-off on long-haul routes. Military aircraft such as the B-52 F and G, KC-135 and the F-105D use water injection as a part of their propulsion system. Favorable overall experience with water injection is keyed to using demineralized water to prevent mineral deposit coating of the compressor blades and combustion cans.

In a 1968 AVLABS report (reference 1), various methods of providing altitude hot day power augmentation were investigated. One of the conclusions reached was that the optimum method was either turbine inlet overtemperature or a combination of turbine inlet overtemperature and compressor inlet water injection or compressor inlet water injection alone in that order of preference. This conclusion was reached on the basis of the various augmentation systems' ability to achieve the augmentation goals; their complexity; any advantages, penalties, and limitations associated with their use; and a merit factor based on the total installed system and fuel weight required to perform a specified mission.

There are two main drawbacks of a water injection system: increased logistics and maintenance requirements over the dry engine powered helicopter. These drawbacks could be at least partialy overcome by increased helicopter productivity requiring fewer aircraft to accomplish a given lift mission and hence, lowered theater-wide logistics and maintenance requirements.

The purpose of this report is to show the potential gains in helicopter hover mission payload capability and take-off performance utilizing the water injection technique for short time periods in the altitude-hot day operational environment. Further benefical compounding effects of both performance items are excluded from this report.

The objectives sought for the application of water injection concept are twofold:

(1) A product improvement item for present day helicopters which have substantial maximum gross weight and transmission power rating margins over the dry engine case. Examples are UH-1H, CH-47B, AH-1G, and CH-53D.

(2) A method of providing additional power when applied to advanced technology engines.

POWER AUGMENTATION

The degree of power augmentation attainable is a function of the following factors (from references 2 through 9).

(1) Ambient temperature

(2) Type of injected fluid, water-alcohol mixture or water alone

(3) Engine compressor type such as axial or centrifugal or a combination of both axial and centrifugal

(4) Fluid injection location such as at the compressor inlet or at some compressor interstage position or both.

(5) Toleration of the engine compressor to the acceptance of the fluid in liquid form without damage

(6) Technique for increasing engine fuel flow during water-on operation

Since the purpose of this report is to explore the potential payoffs afforded by the water injection concept, a discussion of the above factors is omitted. Typical power augmentation values are shown in Figure 1 which were derived from references 2 through 9.

RESULTS

UH-1H payloads were computed for radius mission operations using take-off gross weights reflecting out-of-ground effect (OGE) hover capability with wet and dry engine power levels. Computations were based on reference 10 data and the power augmentation curves of Figure 1. Empty weight was increased 60 lb (27.2 kg) for the wet engine case to allow for the onboard water injection system. The radius mission was defined as

- 2 min. warm up at normal rated power
- 2 min. at maximum power for hover, take-off and climbout
- Cruise outbound at recommended cruise speed at take-off altitude
- 2 min. at hover power for landing
- Unload all cargo
- 2 min. at hover power for take-off and climbout
- Cruise inbound at recommended cruise speed
- Land with 10% fuel reserve

Water was consumed on the outbound take-off and landing segments of the mission as required. Consumed water weight was not considered as part of the payload.

Take-off gross weights, payloads and water loads are presented in Figures 2 and 3 for a 50 n. mi. (92.6 km) radius mission. These data show the large increases in mission payloads obtainable on hot or warm days at altitudes above sea level. Only relatively small water loads are required due to the short water utilization time. Wet engine payload to dry engine payload ratios are shown in Figure 4 for various radius missions. Also shown are the ratios of the number of wet engine aircraft trips to the number dry engine aircraft trips required to move a given amount of cargo.

For example, with OGE hover operations at 5000 ft (1525 m) 35°C for a 50 n. mi. (92.6 km) radius mission

	dry engine	wet engine
Take-off gross weight, lb (kg)	7700 (3492)	9124 (4140)
Payload, lb (kg)	1427 (647)	2666 (1180)
Water load, lb (kg)	0	98 (44.5)
Number of trips to transport 142,700 lb	100	53.6

Another illustrative example is the CH-47B operating over a 50 n. mi. (92.6 km) radius with sling loaded cargo as the payload on the outbound leg and a 3000 lb (1360 kg) internal cargo carried on the return leg. The sling loaded cargo was the payload worth factor sought. The radius mission was defined as

2 min. warm-up at normal rated power

4 min. OGE hover, pickup external cargo (includes take-off and acceleration to cruise speed)

Cruise outbound at hover altitude and temperature conditions at 70 knots referred airspeed

4 min. OGE hover at take-off altitude and temperature conditions to position and drop external cargo

Land and load 3000 lb (1360 kg) of internally stowed cargo

2 min. warm-up at normal rated power

Take-off and cruise inbound @ 99% best range speed at take-off altitude

Land with 10% fuel reserve

Take off cross weights depicted in Figure 5 reflect both augmentation limits for OGE hover and a normal rated power limit for the outbound cruise. The take-off gross weight reflecting normal rated power limit was defined as normal rated power gross weight plus hover fuel and water plus warm-up fuel. Empty weight was increased 112 lb (50.8 kg) as an allowance for the onboard water injection system. Consumed water weight was not considered as part of the payload. Power required on the outbound cruise leg reflected a 100 ft^2 (9.3 m^2) equivalent flat plate area drag of the sling loaded cargo plus optimum vehicle sideslip. Mission computations were based on reference 11 and 12 data and the power augmentation values of Figure 1.

Comparative sling loaded payloads for the wet and dry engine cases in Figure 6 illustrate the potential payload gains attainable with rising ambient temperature. Water loads for the two 4 min. hovers were small and are also included in Figure 6. Figure 7 depicts wet to dry engine payload ratios and also the ratio of the number of aircraft trips required to transport a given cargo for the wet and dry engine cases respectively. For example with the CH-47B operating at 6000 ft (1830 m) 35°C over a 50 n.mi. radius

	dry engine	wet engine
Take-off gross weight lb (kg)	31700 (14380)	37043 (16800)
Outbound payload lb (kg)	9100 (4130)	13600 (6160)
Water load lb (kg)	0	462 (209.5)
Number of trips to transport 91000 lb (41300 kg)	10	6.7

A second major benefit is better take-off performance as a consequence of more power available. This is especially significant for gross weights exceeding the dry power OGE hover weight, that is, at in-ground-effect (IGE) hover gross weights. Take-offs at IGE hover weight are best performed by first accelerating to forward speed, then rotating and climbing out with power margin to assure safe ascent. This technique would require 950 ft (290 m.) to clear a 50 ft (15.25 m) obstacle for a dry powered 9124 lb (4140 kg) UH-1H at 5000 ft (1525 m) 35°C conditions. Less than 100 ft (30.5 m) is required using wet power with the OGE hover capability.

Another significant performance item is better maximum performance climb as illustrated in Figure 8 for the 9124 lb (4140 kg) UH-1H. A 71% improvement in rate of climb is achieved at a water flow rate of 34 lb per minute (15.4 kg per minute).

CONCLUDING REMARKS

Water injection has been shown to be a concept which can improve the performance of helicopters when more shaft power can be effectively utilized for short durations. The major direct effect is greatly increased transport mission payloads with a consequent increase in takeoff performance and maximum performance climb capability in altitude hot day conditions.

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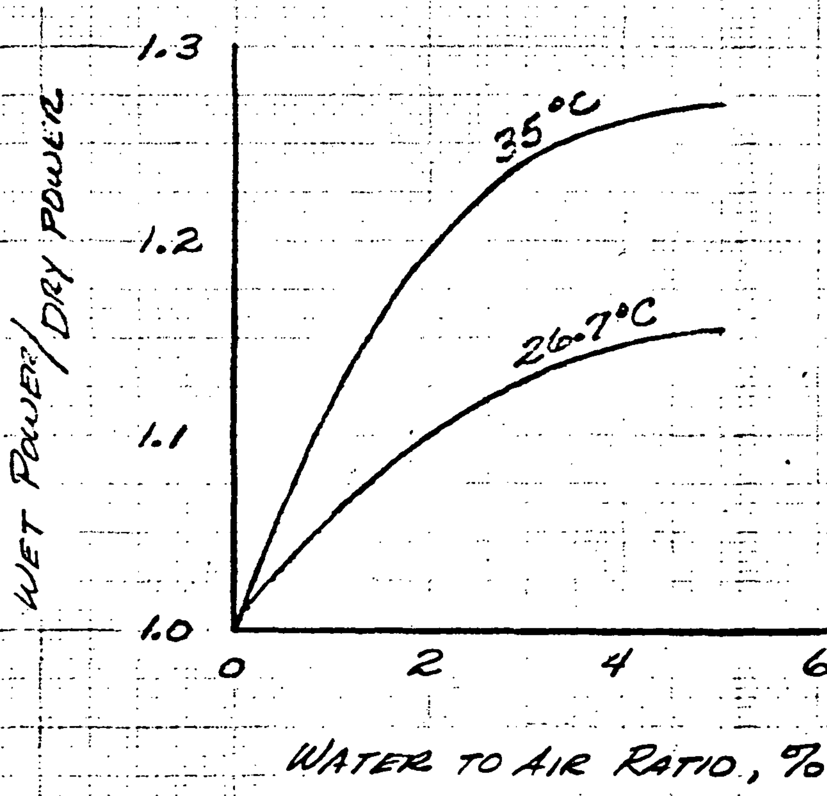

FIGURE 1 AUGMENTED POWER RATIO

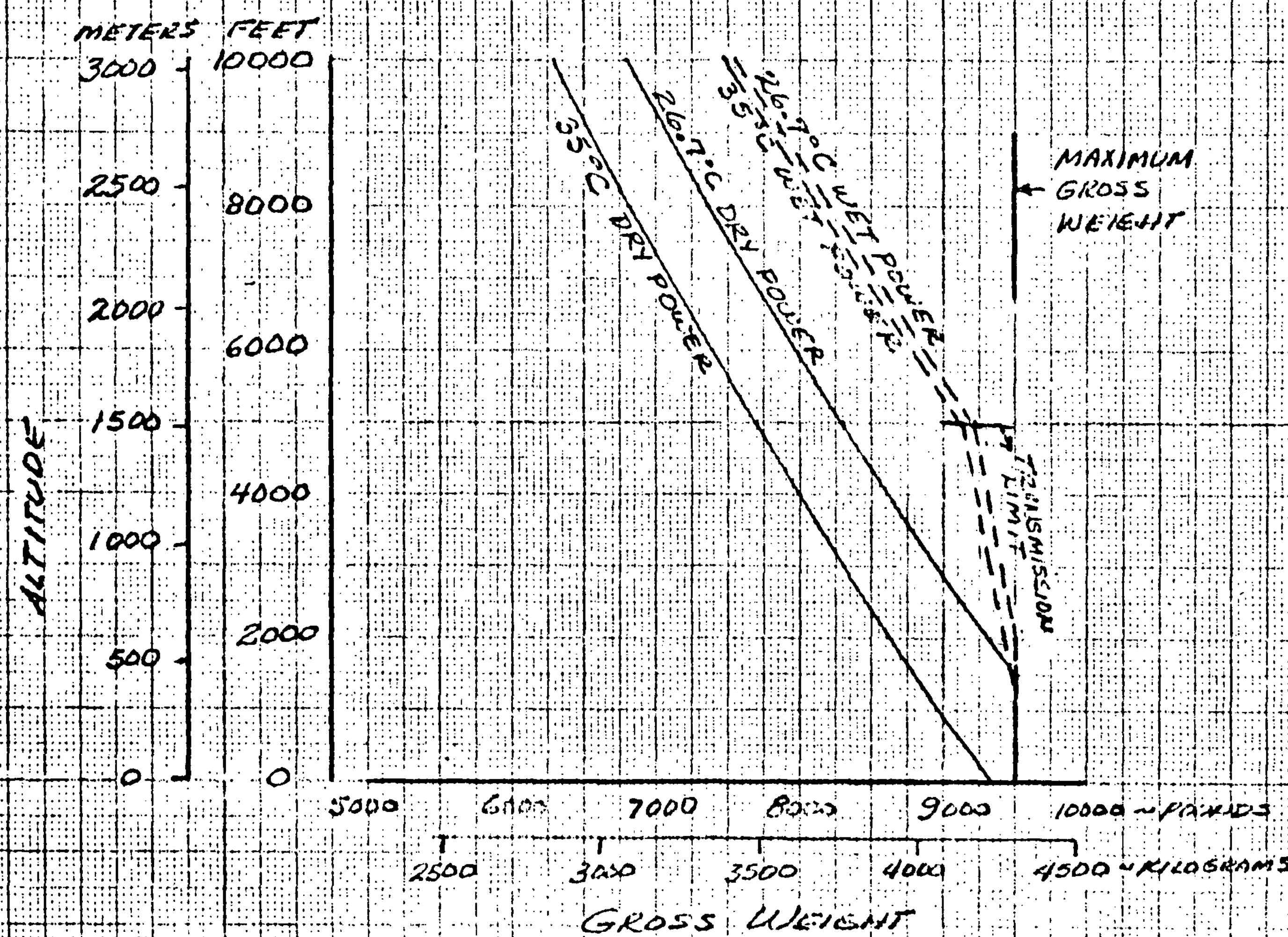

FIGURE 2 UH-1H MISSION TAKE-OFF GROSS WEIGHT

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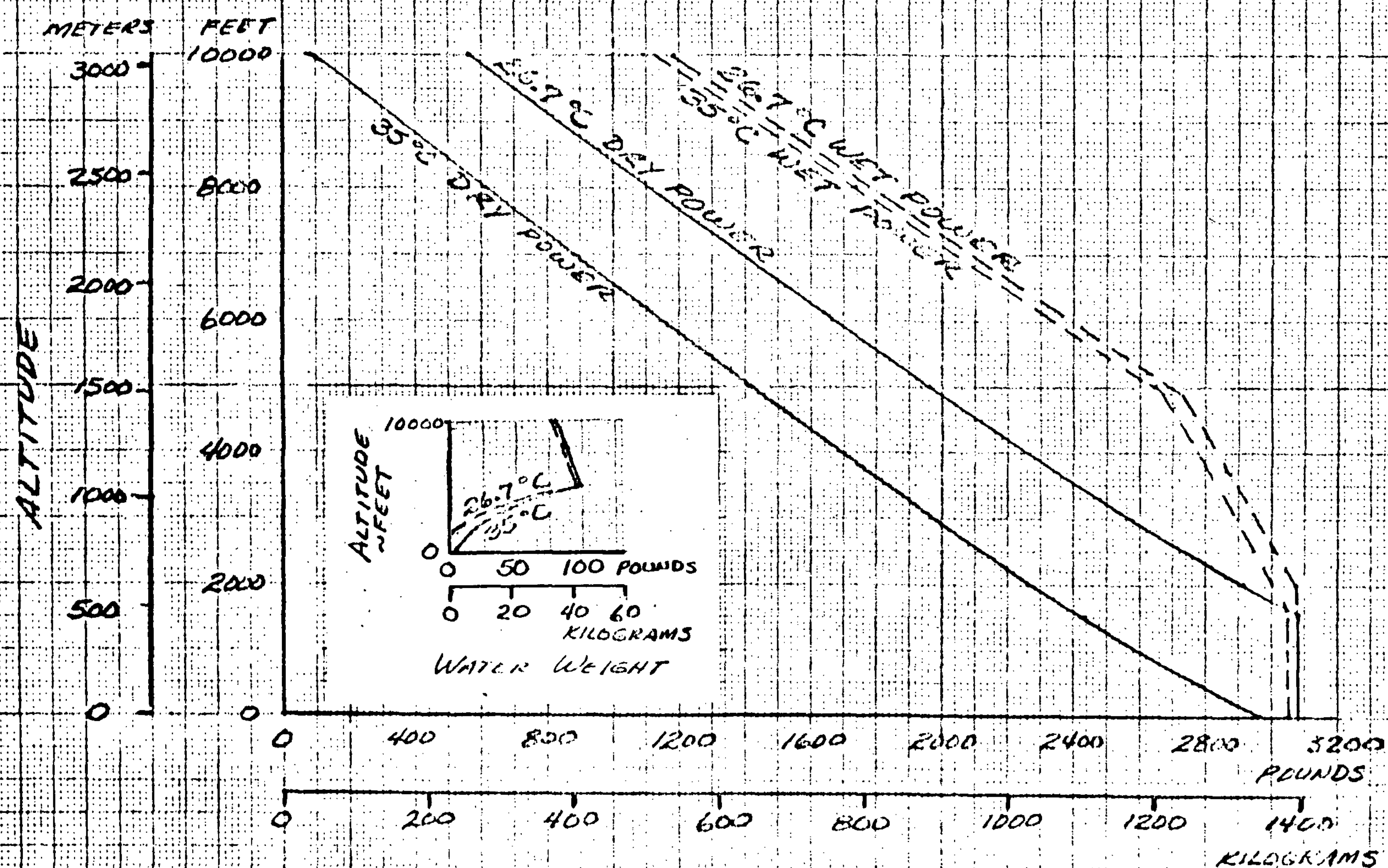

FIGURE 3 UH-1H MISSION PAYLOAD AND WATER WEIGHT VARIATION WITH ALTITUDE AND AMBIENT TEMPERATURE

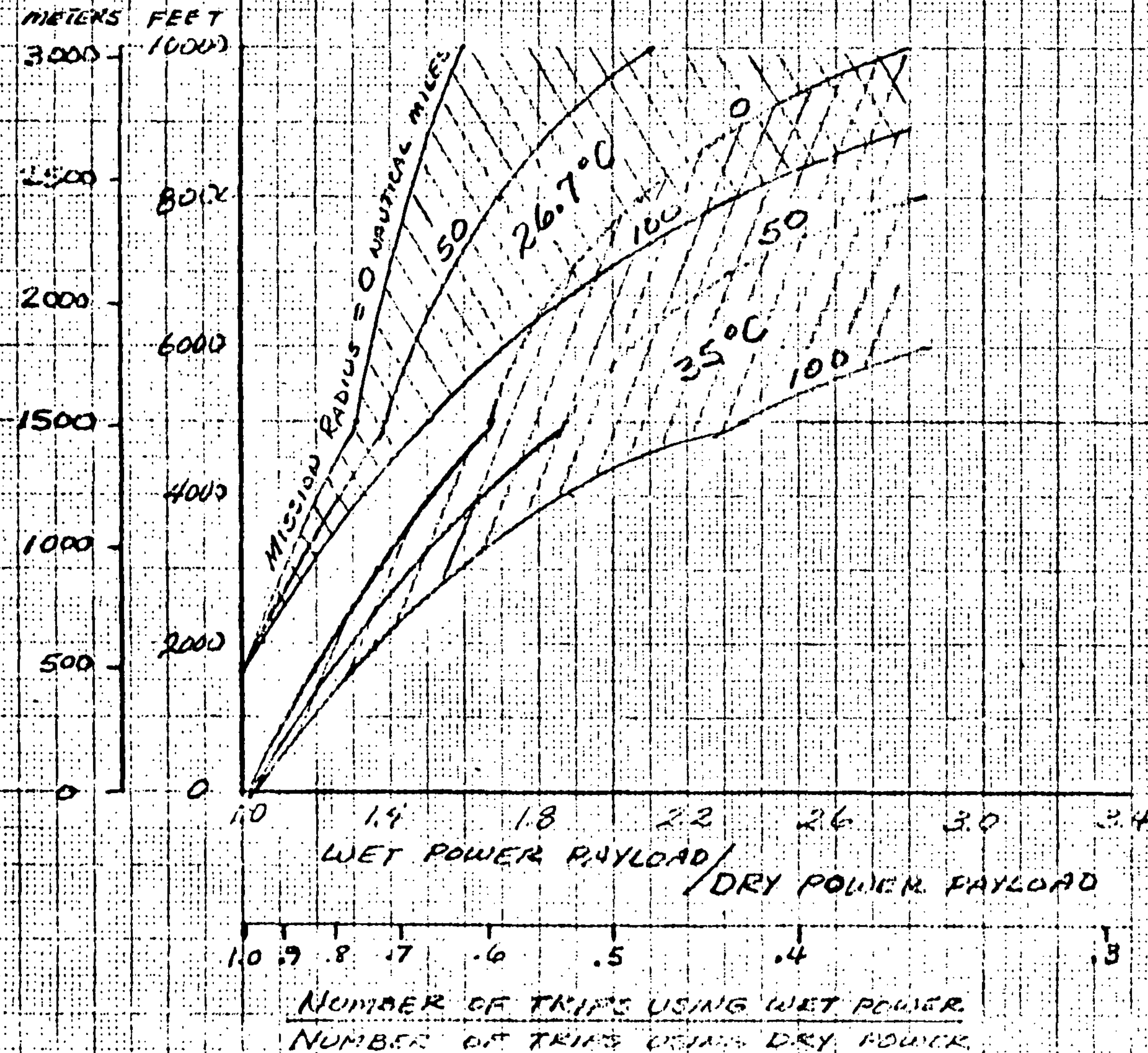

FIGURE 4 VARIATION OF UH-1H PAYLOAD RATIO AND TRIP RATIO WITH MISSION ALTITUDE AND AMBIENT TEMPERATURE

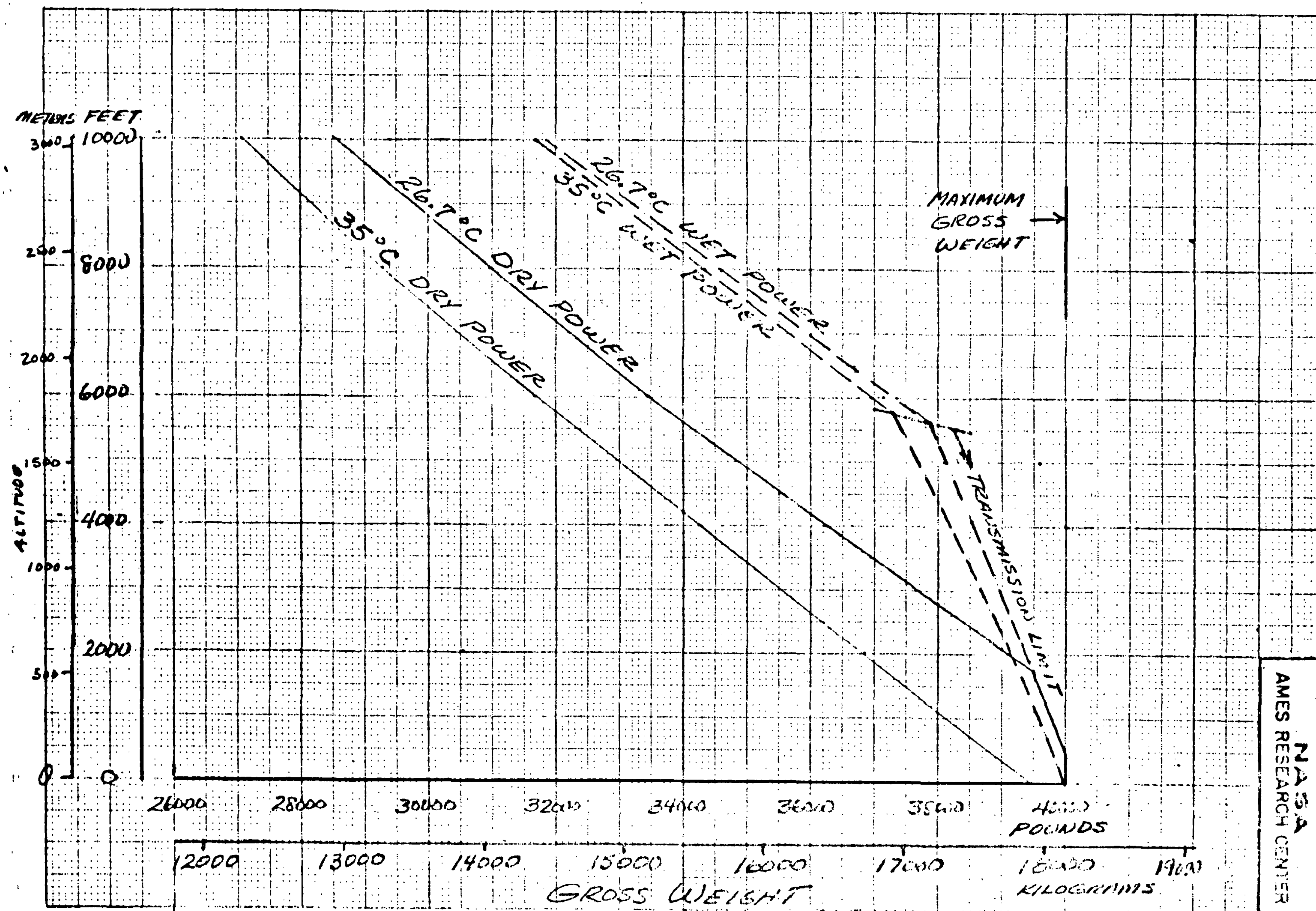

FIGURE 5 CH-47B MISSION TAKE-OFF GROSS WEIGHT

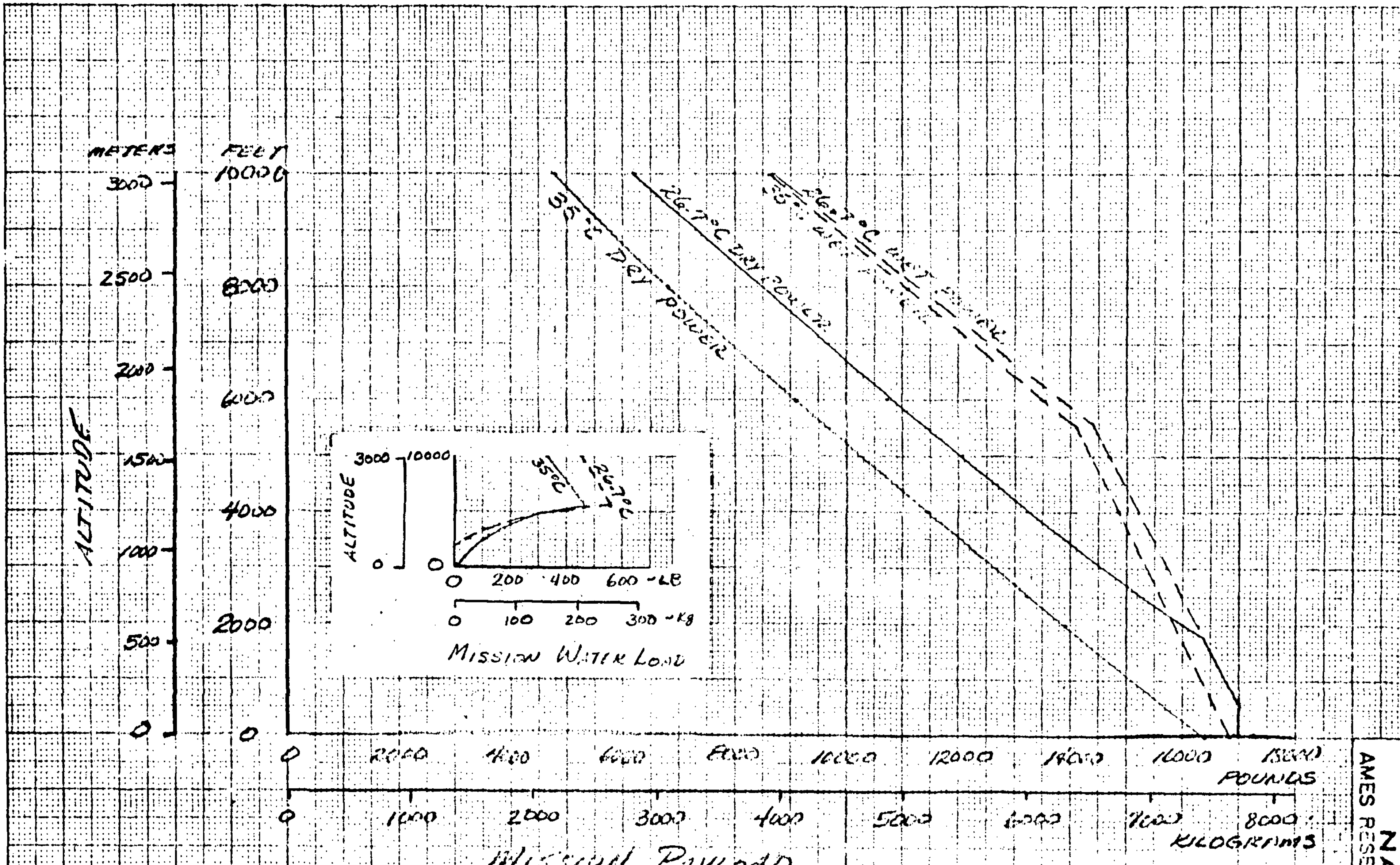

FIGURE 6 CH-47B PAYLOAD AND WATER LOAD FOR 50 NAUTICAL MILE (92.6 KILOMETER) RADIUS MISSION

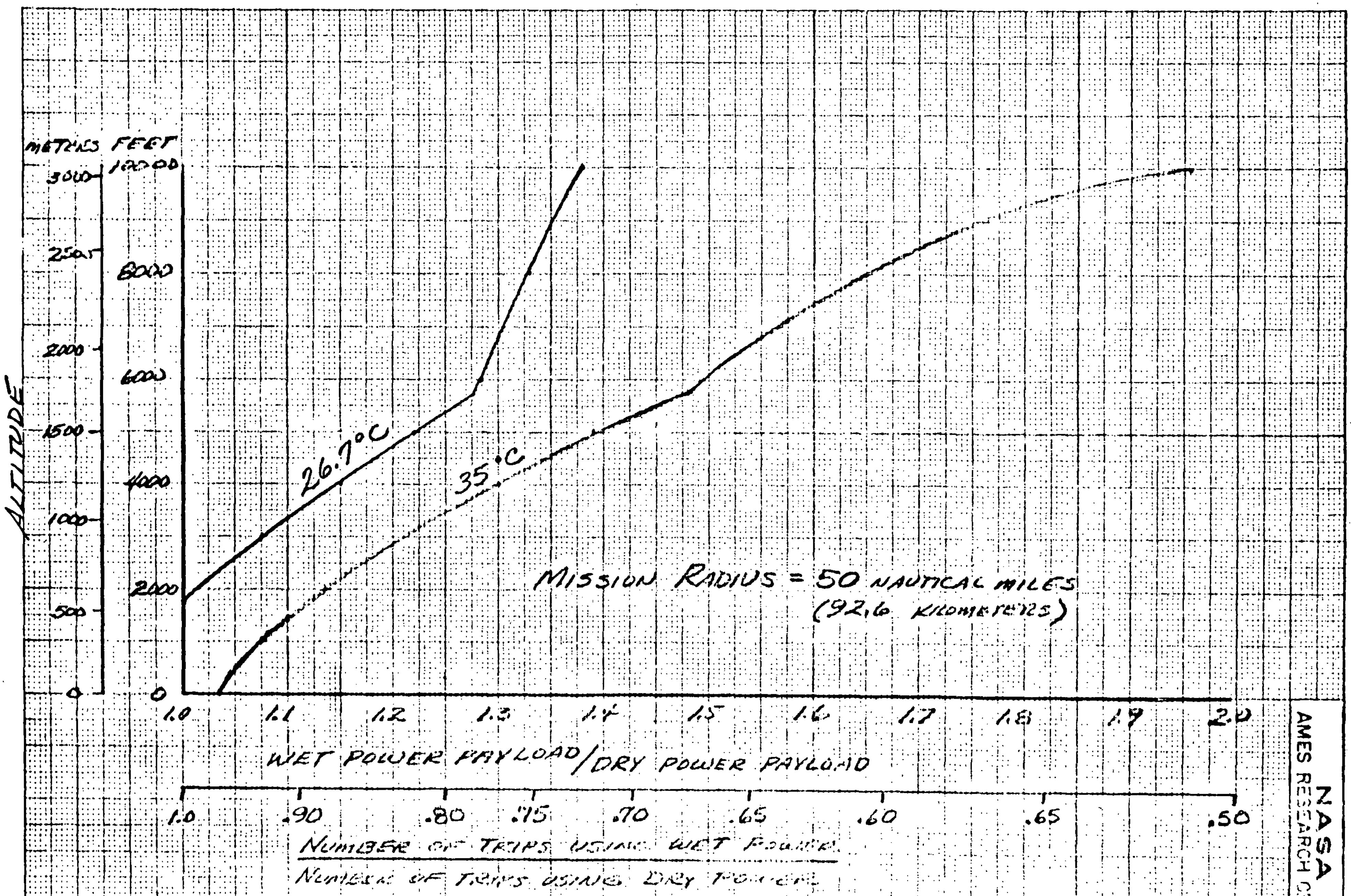

FIGURE 7 VARIATION OF CH-47B PAYLOAD RATIO AND TRIP RATIO WITH MISSION ALTITUDE AND AMBIENT TEMPERATURE

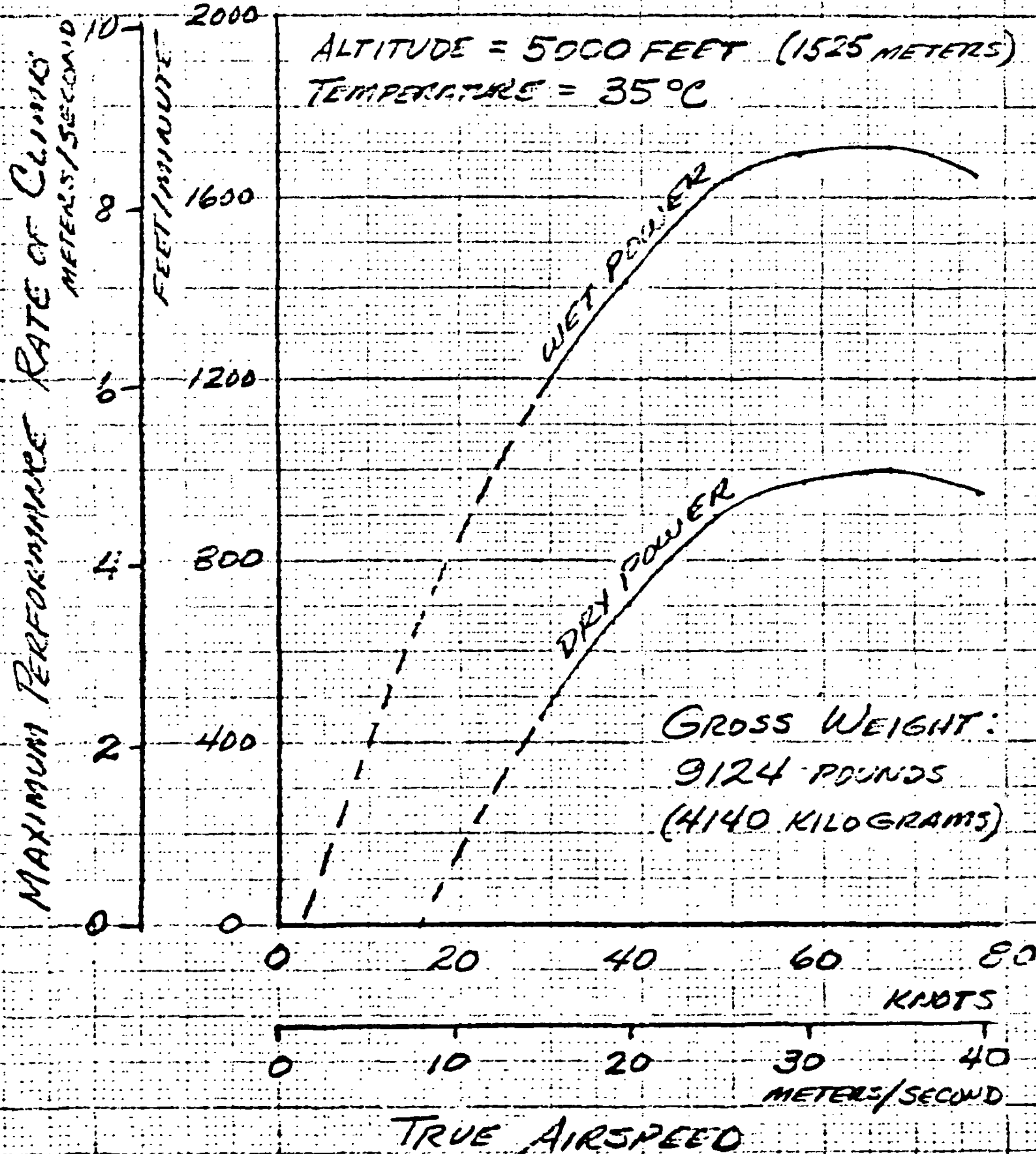

FIGURE 8 UH-1H MAXIMUM PERFORMANCE CLIMB CAPABILITY WITH WET AND DRY POWER