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THE VTX DUTY CYCLE DEVELOPED FROM T-2C AND TA-4J ENGINE USAGE DATA

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A T-2C and a TA-4J aircraft were suitably instrumented for recording engine usage data. These aircraft flew typical training profiles which were obtained via pilot interviews. Based on flight data, the duty cycles were calculated for each trainer to establish design requirements which apply to the VTX system. A VTX duty cycle was developed from this study.

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SUMMARY

A T-2C and a TA-4J aircraft were suitably instrumented for recording engine usage data. These aircraft flew typical training profiles which were obtained via pilot interviews. Based on flight data, the duty cycles were calculated for each trainer to establish design requirements which apply to the VTX system. A VTX duty cycle was developed from this study.

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INTRODUCTION

The Navy plans to replace the current intermediate and advanced jet trainers (T-2C and TA-4J) with a single new vehicle designated the VTX. Additionally, the VTX power plant is to be designed for high reliability to keep its life cycle cost at a minimum.

To ensure an engine of high reliability, the engine specification must define the expected duty cycle so that testing will reflect anticipated operational experience. From a review of the proposed VTX systems, it was very likely that the power plant would be "off the shelf" and not necessarily qualified to recently revised Navy specifications.

The Naval Air Development Center has established a duty cycle data base which includes fighter, attack, patrol, early warning and training aircraft. NAVAIRSYSCOM has made frequent use of this Center's expertise on several other engine programs (see references a through e) and requested, by reference f, a VTX duty cycle based on current jet trainer flight data. These results will be used to assess the engine component part lives and design future accelerated mission test schedules.

BACKGROUND

CURRENT JET TRAINERS

The Naval Aviation Training Command provides undergraduate pilots for the fleet replacement squadrons. Its current program is conducted in three phases: primary, intermediate and advanced. The student pilot generally flies the T-2C aircraft during the intermediate phase and the TA-4J aircraft while completing the advanced phase. The T-2C is a two-place, subsonic, land and carrier-based trainer powered by twin J85-GE-4 turbojet engines. The TA-4J is a two-placed, subsonic, land and carrier-based trainer powered by a single J52-P-8 turbojet engine.

CURRENT ENGINES

The J85-GE-4 is a compact, lightweight engine containing an eight-stage axial flow compressor coupled directly to a two-stage turbine. It incorporates controlled interstage air bleed, variable inlet guide vanes, a through-flow annular combustor, a fixed-area concentric exhaust nozzle, and an integrated control system. The engine is rated at 2950 pounds (military power) thrust at sea level standard conditions. It completed the 150 hour endurance test (MQT) for Navy qualification in May 1966.

The J52-P-8 is an axial-flow engine with a multi-stage reaction turbine. It has nine through-flow combustion chambers in an annular arrangement. The multi-stage axial compressor consists of a five-stage low pressure unit and a seven-stage high pressure unit. Both compressors are directly coupled to a single stage turbine. This engine is rated at 8500 pounds (military power) thrust under sea level standard conditions. It completed the 150 hour endurance test (MQT) for Navy qualification in June 1965.

APPROACH

SQUADRON SURVEY

Pilots were surveyed to elicit detailed information concerning mission profiles and standard operating procedures. Visits were made to the squadron locations, as shown before in reference a, to discuss the following topics: land-based training missions, trim checks, NATOPS procedures, engine limits, etc.

Each squadron and respective maintenance shop provided their personnel in support of the survey. They answered questions freely and explained both their procedures and problems to any degree required by the interview. Table I lists the squadrons visited by their respective locations.

Table I. Trainer Squadrons Visited by Location

Base Locations	T-2C Squadrons	TA-4J Squadrons
NAS Pensacola, FL	VT-4, -10	VT-86
NAS Meridian, MS	VT-9, -19	VT-7
NAS Kingsville, TX	VT-23	VT-21, 22
NAS Chase, TX	VT-26	VT-24, 25

TRAINING SYLLABUS

Pilots in each squadron follow a specific flight training syllabus. This syllabus contains numerous mission types for each aircraft. For the T-2C, there were seven mission types. The TA-4J syllabus had eight mission types. Along with the type of missions, the syllabus provided the number of flight hours that a student pilot will accumulate. Hence, the frequency of occurrence based on hours was also available in the training syllabus. Table II presents the training syllabus data for the T-2C and the TA-4J.

Table II. Jet Trainer Mission Types and Occurrence

T-2C Mission Types	Percent of Total Time	TA-4J Mission Types	Percent of Total Time
Familiarization	31.5	Familiarization	13.6
Basic Instruments	4.5	Instruments	7.9
Radio Instruments	4.5	Formation	10.1
Formation	24.0	Low Level Navigation	4.5
Navigation	13.5	Airways Navigation	19.1
Gunnery	12.0	Air-Air Combat	12.3
Carrier Qualification	10.0	Air-Ground Weapons	14.6
		Carrier Qualification	17.9
	100.0		100.0

GROUND RUN PROCEDURES

Each power plant maintenance shop was visited to determine if ground runs do contribute significantly to the duty cycle. Low power engine operation associated with aircraft power-up were cited as very infrequent. However, when trims were mentioned, personnel said they may check 2-3 engines per week, and further stated that the duration of the trim runs could vary from 30 to 90 minutes. For duty cycle calculations, an average value was assumed to account for ground runs.

AIRCRAFT INSTRUMENTATION

The T-2C aircraft was instrumented at this Center to record engine usage and flight conditions. A Datel model DL-2R2 data logger described in reference g was selected; it continuously records up to 64 parameters of analog data on Phillips-type cassettes. Housed in a sealed, weather-proof metal case, the logger will operate for more than one year on its own lithium battery power supply. Additionally, military type connectors were provided for all analog input channels, which allowed easy interface with aircraft circuits.

Two additional provisions were made to ensure safe operation of the logger during flight tests. A two-way pressure relief valve permitted flushing of the case with dry air or nitrogen before each flight to prevent moisture build-up. Also, a thermostatically-controlled heater was incorporated to allow operation down to a temperature of -50°C.

The TA-4J aircraft was instrumented at the Naval Air Test Center (see reference h) for measurement of engine usage through the parameters listed in Table III. A ten watt FM transmitter was used to relay the acquired usage data to the telemetry ground station. At the completion of each flight, a digital computer tape was made and sent to this Center.

There were two main reasons for selecting this mode of instrumentation. A telemetry package was smaller and cheaper to install than the equivalent on-board recorder, and it was immediately available for use in the proposed aircraft. Shelves were built into the port and starboard wheel-wells for the telemetry package. The lower antenna was mounted on the port gun fairing and the upper antenna was mounted behind the cockpit.

IN-FLIGHT MONITORING

Both aircraft were flown on the missions resulting from the squadron survey. Aircraft configurations matched that of the squadron aircraft. For the T-2C, three pilots were available to produce data. On the TA-4J, one pilot was available to produce data.

Each monitored flight yielded a full record of engine usage. These data were then reduced and analyzed to provide the basis for developing the duty cycles.

Table III. List of Instrumentation Parameters

1. Low Pressure Rotor Speed
2. High Pressure Rotor Speed
3. Power Lever Angle
4. Outside Air Temperature
5. Exhaust Gas Temperature
6. Engine Pressure Ratio
7. Turbine Exit Pressure
8. Burner Pressure
9. Altitude
10. Air Speed
11. Event Marker
12. Inlet Total Pressure

DISCUSSION OF RESULTS

MISSION PROFILES

Discussions regarding mission details at each squadron showed consistency among most pilots. Some differences in local base operations were noted and accounted for in the assembly of representative training missions. Tables IV and V list these resulting profiles for the T-2C and the TA-4J respectively. When questioned about changes to NATOPS defined engine limits, pilots said that none currently exist. They are free to select any of the available power settings to perform their aerial maneuvers.

USAGE DATA REDUCTION

The flight data was reduced by computer programs developed previously in reference a. Tabular data was plotted to allow sufficient editing of each parameter. Some spurious data was removed before the usage content was assessed. Subsequently, counting programs summed the number of starts, throttle cycles, and hot time during each flight. These results were then used to compute the duty cycle.

Table IV. T-2C Training Mission Profiles

Familiarization
1) Warmup - 15 minutes.
2) Takeoff and climb to 15,000 feet.
3) Cruise - 15 min. at 250 knots.
4) Maneuvers: minimum radius turns, acrobatics, stall series, and vertical recoveries.
5) Cruise back to base - 15 min. at 250 knots.
6) Touch and go 5 times and land.

Basic Instruments
1) Warmup - 15 minutes.
2) Takeoff and climb to 10,000 feet.
3) Maneuvers: NATOPS S-3 and yoke pattern, half standard rate turns, stall series and unusual attitudes.
4) Climb to 16,000 feet, TACAN penetration to a missed approach.
5) Ground controlled approach and land.

Radio Instruments
1) Warmup - 15 minutes.
2) Takeoff and climb to 10,000 feet.
3) Maneuvers: radio intercept, station passage, point to point navigation, and ground speed check.
4) Climb to 16,000 feet, TACAN penetration to a missed approach.
5) Ground controlled approach and land.

Formation
1) Warmup - 15 minutes.
2) Takeoff and climb to 15,000 feet.
3) Maneuvers: parade formation, cross-unders, lead changes, rendez-vous, under-runs, parade turns, cruise turns.
4) Descent to a ground controlled approach.
5) Touch and go 5 times and land.

Navigation
1) Warmup - 15 minutes.
2) Takeoff and climb to 15,000 feet.
3) Cruise - 20 min. at 250 knots and descend to 2,500 feet.
4) Low level navigation - 30 minutes at 320 knots.
5) Ground controlled approach and land.

Gunnery
1) Warmup - 15 minutes.
2) Takeoff and climb to 15,000 feet.
3) Cruise for 20 minutes at 250 knots.
4) Gunnery practice for 30 minutes at 300 knots.
5) Cruise to base at 250 knots.
6) Ground controlled approach.
7) Touch and go 5 times and land.

Carrier Qualifications
1) Warmup - 15 minutes
2) Takeoff and climb to 5,000 feet.
3) Cruise to ship - 10 minutes at 220 knots.
4) Land 6 times, 60 minutes
5) Cruise to base - 10 minutes at 220 knots.
6) Ground controlled approach.
7) Land

Table V. TA-4J Training Mission Profiles

Familiarization
1) Warmup - 20 minutes.
2) Takeoff and climb to 15,000 feet.
3) Maneuvers: 30°, 45°, 60° turns, manual fuel selections, stall series, acrobatics.
4) Descent to 2500 feet and missed approach.
5) Landing series for 15 minutes.

Instruments
1) Warmup - 20 minutes.
2) Takeoff and climb to 20,000 feet.
3) Maneuvers: NATOPS S-3 and yoke patterns, unusual attitudes.
4) TACAN penetration to a missed approach.
5) Ground controlled approach and land.

Formation
1) Warmup - 20 minutes.
2) Takeoff and climb to 20,000 feet.
3) Maneuvers: cross-unders, parade turns, break-up and rendez-vous.
4) Cruise in column formation, 20 minutes.
5) Gun-sight tracking for 10 minutes.
6) Descend and land.

Low Level Navigation
1) Warmup - 20 minutes.
2) Takeoff and climb to 5000 feet.
3) Cruise for 10 minutes at 300 knots.
4) Descend to 1000 feet and cruise at 360 knots, 50 minutes.
5) Climb to 5000 feet and cruise back to base.
6) Land.

Airways Navigation
1) Warmup - 20 minutes.
2) Takeoff and climb to 30,000 feet.
3) Cruise for 80 minutes at Mn = .65.
4) Descent to 15,000 feet.
5) TACAN approach and land.

Weapons Delivery
1) Warmup - 20 minutes.
2) Takeoff and climb to 10,000 feet.
3) Cruise for 10 minutes at 300 knots.
4) Bombing runs - 10°, 30°, 45° dive angles, 9-10 runs.
5) Cruise to base for 10 minutes.
6) Ground controlled approach and land.

Air Combat Maneuvers
1) Warmup - 20 minutes.
2) Takeoff and climb to 18,000 feet.
3) Cruise for 10 minutes at 300 knots.
4) Combat for 10 minutes with 3 engagements
5) Cruise back to base.
6) Visual flight rules approach and land.

Carrier Qualifications
1) Warmup - 20 minutes.
2) Takeoff and climb to 4,000 feet.
3) Cruise to ship at 275 knots.
4) Land 6 times, 60 minutes.
5) Cruise back to base at 275 knots.
6) Visual flight rules approach and land.

DUTY CYCLE ANALYSIS

The duty cycle for the T-2C/J85 was computed using the seven missions, a maintenance trim, and the flight data. Similarly, the duty cycle for the TA-4J/J52 was calculated using eight missions, a maintenance trim, and the flight data. Thus, for a 1000 hours operating time, the resulting total number of starts, throttle cycles, and hot time are shown in Table VI.

Table VI. Duty Cycle 1000 Hr. Summaries

Aircraft Type/Model	Number of Starts	Throttle Cycles	Hot Time (hr.)
T-2C	666	4027	83.4
TA-4J	524	4480	116.0

Notably, the T-2C duty cycle has a higher cyclic content than the TA-4J due to the greater number of missions (or start-stop cycles). This was principally because of a lower average flight time for the T-2C. Conversely, the TA-4J shows significantly more hot time, because the TA-4J is used exclusively for air combat maneuvering practice and air-ground weapons delivery. These two missions tend to drive the duty cycle because of their large hot time content.

The development of the duty cycle for a VTX trainer aircraft must be viewed from a new perspective. The previous analysis shows the T-2C used in one manner, and the TA-4J used in a significantly different one. Since the VTX aircraft will be used in both roles, it will be required to function under both requirements at once. Thus, the highest values must be used to define the expected duty cycle for the VTX propulsion system. Table VII defines the duty cycle for the VTX.

Table VII. VTX Duty Cycle Definitions

Number of Starts	Throttle Cycles	Hot Time (hr.)
666	4480	116.

CONCLUSIONS

Mission profiles and maintenance procedures for the T-2C/J85 intermediate trainer and the TA-4J/J52 advanced trainer were investigated. A test aircraft of each model was instrumented to provide recorded usage data over the surveyed missions. From the engine usage tapes, a data base has been established from which to develop a trainer duty cycle.

The duty cycle for the present J85-GE-4 and J52-P-8 was calculated. Using the most demanding criteria from both data, a duty cycle was derived for the proposed VTX replacement trainer aircraft. When the Navy acquires the new trainer engine, the propulsion system specification should include this VTX duty cycle as a more realistic design criteria. Any future mission tests should also be compared with this criteria to reveal their usage severity.

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