CONFIDENTIAL

AVRO VTOL PROGRAM

RECOMMENDED TASKS IN GENERAL ORDER OF PRIORITY

1. Weapon System Studies. These studies would investigate the capability of the AVRO concept to meet existing GOR's with initial emphasis upon the dispersed site Fighter Bomber. The unique capability of the system to accomplish this and other fundamental Air Force missions such as Tactical Bombing, aerial resupply, etc. will also be considered. Estimated costs for these studies, which would be accomplished on a continuing basis, is approximately $200,000.

2. Wind Tunnel Tests. AVRO has stated that the present dual inlet (top and bottom) configuration utilizing a counter-rotating squirrel cage rotor system is not optimum and that a propulsion system similar to the AVROCAR and utilizing only a top inlet would be more desirable for future weapon systems. Wind tunnel tests are planned to include supersonic air intake pressure recovery and reflection plane models to obtain data on new configurations generated by the weapon system studies. Simulation of inlet and diffuser will be accomplished if a suitable model can be constructed. Estimated cost of these tests is approximately $150,000.

3. The propulsive nozzle system proposed for the AVROCAR is unsuitable for a supersonic type vehicle. Tests are needed to evaluate effectiveness of a supersonic type nozzle in producing propulsive thrust and control moments. It is planned that a nozzle, approximately full scale, will be installed in the AEDC facility so that internal and exit air flow can be simulated with supersonic flow over the outer surface. These tests are estimated to cost $115,000.

4. Propulsion system analyses are planned to include an analysis of the AVROCAR type rotor which AVRO now recommends for incorporation in future supersonic type aircraft. These studies would include design and off design point characteristics, control system, transient studies, etc. Specific information to be obtained will include compressor and turbine maps, weight estimates, performance parameters, combustion and fuel system specifications. Estimated cost for this analysis is approximately $50,000.

5. Stability and Control Analyses and Tests. This would include tests to determine means for controlling exit air flow for stability control purposes to include considerations of efficiency, linearity, resolution, frequency response complexity, reliability, etc., analyses of stability problems associated with various flight conditions, investigations of stability derivatives and dynamic characteristics, analogue computer studies, etc. Estimated cost approximately $250,000.

6. The AVROCAR will not, of course, incorporate provisions for afterburning in the outer wing as will be required for supersonic flight. Testing of combustion chambers on the six viper test rig could provide useful data for a later supersonic aircraft. Construction of a section of the outer wing (1/6 of complete wing) and installation and test on the six viper rig is estimated to cost approximately $200,000.

CONFIDENTIAL

7. Investigation of the possibility of eliminating the vertical rotor from the propulsion system internal flow path during high speed flight as an alternative to designing the rotor using supersonic compressor technique with its inherent penalty in the low speed condition.

200000
150000
115000
50000
250000
200000
—
$ 965,000

Approx Cost $1M

OBSERVATIONS CONCERNING THE AVRO CIRCULAR PLANFORM AIRCRAFT

I. Aerial Jeep Mission

Military opinion is that this mission involves flight predominantly in the speed range 0-50 mph. In this regime the power required is close to that necessary for hovering (see fig. 1). The fuel consumption at or near full power, coupled with the low forward speed implies a very low mileage per gallon of fuel.

This observation is true of all low speed flying vehicles (except aerostats); however those vehicles that handle a large mass flow of air are fundamentally superior to those using relatively little. The least suitable design for this mission would be a direct jet-lift vehicle (such as the Rolls Royce Bedstead); the best from this point of view would be a helicopter. The Avrocar is superior to direct jet lift, but in terms of lift per horsepower it is at the low end of the scale (see fig. 2). Other designs proposed for this mission, such as the US ducted-fan aerial jeeps, are fundamentally inferior to the helicopter in economy, but much better than the Avrocar.

The seriousness of this factor is indicated by calculations of fuel consumption of the Avrocar at a mean speed of 25 mph. This gives a "mileage" of about 150 yards per gallon: i.e., full tanks (148 gallons) would be adequate for only 12 miles without any allowances or reserves. A favourable ground effect of the magnitude observed statically is allowed for.

II. Moderate Speed Missions

In moderate speed missions (about 200 mph) the Avrocar naturally gives much better performance than in the low-speed aerial jeep role. However the Avrocar is here in competition with designs having wings designed for efficient cruise. Even assuming equality in the other aerodynamic parameters (an assumption that appears to favour the Avrocar) since the optimum lift/drag ratio is proportional to the square root of the aspect ratio, the Avrocar is at once at a disadvantage of more than 2:1 in aerodynamic cruise efficiency.

III. High Speed Missions

Using wind tunnel test data for the supersonic version, the best lift/drag ratio, which obtains at subsonic speed, is about 4. With the Avro value of C_{D_o}, which is less than half the measured value, the L/D ratio rises to just under 6. Other supersonic configurations give L/D ratios of about twice this amount at subsonic speeds. The same relationship holds with the quantity , which enters directly into the range equation. The low wing-loading also adversely affects range.

Given sufficient thrust for VTOL, high performance is to be expected. However a designer faced with a mission requirement must select the most efficient configuration for the job. It is clear from the remarks above that the Saucer configuration does not compare favourably with more orthodox designs that might be considered for a high speed VTOL mission, in terms of optimum aerodynamic cruise efficiency.

The thermodynamic cycle of the Avro vehicle is at its best under maximum range conditions, and ideally is more efficient than a simple jet engine. Some of this theoretical advantage may remain after turning and ducting losses are accounted for but this remains to be demonstrated. In any event, a conventional bypass cycle, without the losses peculiar to the Avro design, could readily be adapted to the competitive configurations.

In supersonic flight using the burners in the bypass stream, the thermodynamic cycle used by Avro is less attractive. Calculations made for the condition of M1.5 at 50000' give the following results:

	AVRO VTOL	TURBOJET SIMPLE	TURBOJET AFTERBURNING	UNITS
Specific fuel consumption	2.1	1.2	2.1	lb/lb/hr
Specific thrust	42	45	85	lb/lb/sec

The Avro cycle with bypass heating thus combines the low specific thrust of the simple turbojet with the high specific fuel consumption of the afterburning engine: i.e., it has the worst features of both. The importance of fuel consumption is obvious; the low specific thrust of the engine affects its physical size and therefore weight. The flight condition governing engine size might be supersonic (climb, acceleration, manoeuvre), or takeoff. The case considered above is typical for the former; if the engine is sized by takeoff it should be noted that the specific thrust of the Avro system is still lower - about 20 lb/lb/sec. Thus in either event the engine weight is likely to be relatively very high. The "engine" in this case includes the whole system of gas generators, compressor wheel, ducting, and bypass heating chambers.

IV. Weights

According to the information at our disposal, not only do the stated component weights appear to be unduly optimistic by comparison with current practice, but the remarkable weight claims appear to be due in part to the omission of allowances for operational equipment that makes up a large part of the weight of any military machine. Indeed in the case of the high speed aircraft there does not appear to be room for any such equipment, so that presumably space would have to be added in the form of pods or some kind of fuselage. This would add not only to the weight but to the drag.

APPENDIX

Some Topics Requiring Research in Support of Avrocar Development

1. Static Ground Effect

Theoretical and experimental studies of the influence of ground proximity on a circular planform body with peripheral and central jets including: (a) proportioning of flows between the jets, (b) optimum diameter of central annulus, (c) optimum exit angles of jets with respect to body centreline, (d) effect on mass flow and compressor, (e) effect of ground irregularities and body pitch angles.
NAE experience in flow visualization should be useful in much of this work.

2. Transition

Studies of transition from hovering to forward flight, and the reverse, both in free air and in proximity to the ground. Of particular interest is the question of whether the observed favourable static ground effect can be maintained through transition until the vehicle is fully wing-supported; also the optimum programming of the transition with varying amounts of wing lift and jet reaction lift. Stability and controllability in this phase are highly important.

3. Control and the Coanda Effect

The subject of the Coanda effect in general is now attracting renewed attention in other countries, and its use in the Avrocar as the primary control mechanism suggests several lines of investigation such as (a) basic studies of mixing and induction of subsonic and supersonic jets in the presence of a curved surface, both statically and in subsonic and supersonic free streams, and (b) ad hoc investigations of the Avro control system to study the optimum location of the spoiler and bleeds; the linearity, power, frequency response, etc., of the system.

4. Aerodynamic Characteristics of Circular Planforms

Little systematic data exists on profiles, thickness, camber, and the effect of jets. Dynamic derivatives in pitch and roll would be valuable. If for example greater t/c ratios could be used in the Avrocar without serious penalty (the jet sheet may suppress any trailing edge separation), the limited cargo capacity of the design could be improved.

5. Radial Duct Diffusion

Study of the efficiency of the diffusion and recontraction process in radial passages of various shapes and the effect of ribs, surface roughness, etc., is important as it affects the overall vehicle economy, and the space remaining inside the wing.

6. Wing-plane Air Intakes

Work already carried out on ducted rotors with the normal to the plane of rotation approximately perpendicular to the free airstream (for example, the NAE fan-in-wing studies) indicates that many problems exist. The now-uniform inflow and duct lip separation require further work.

Review

OF PV-704/606A PROGRAM

UNCLASSIFIED

PURPOSE

- REVIEW OF PV-704/606A PROGRAM
- EVALUATION OF AVRO CAR PROPOSAL
- RECOMMENDED USAF/ARMY INTEGRATED PROGRAM

UNCLASSIFIED

3-242

JOINT EFFORT PROGRAM

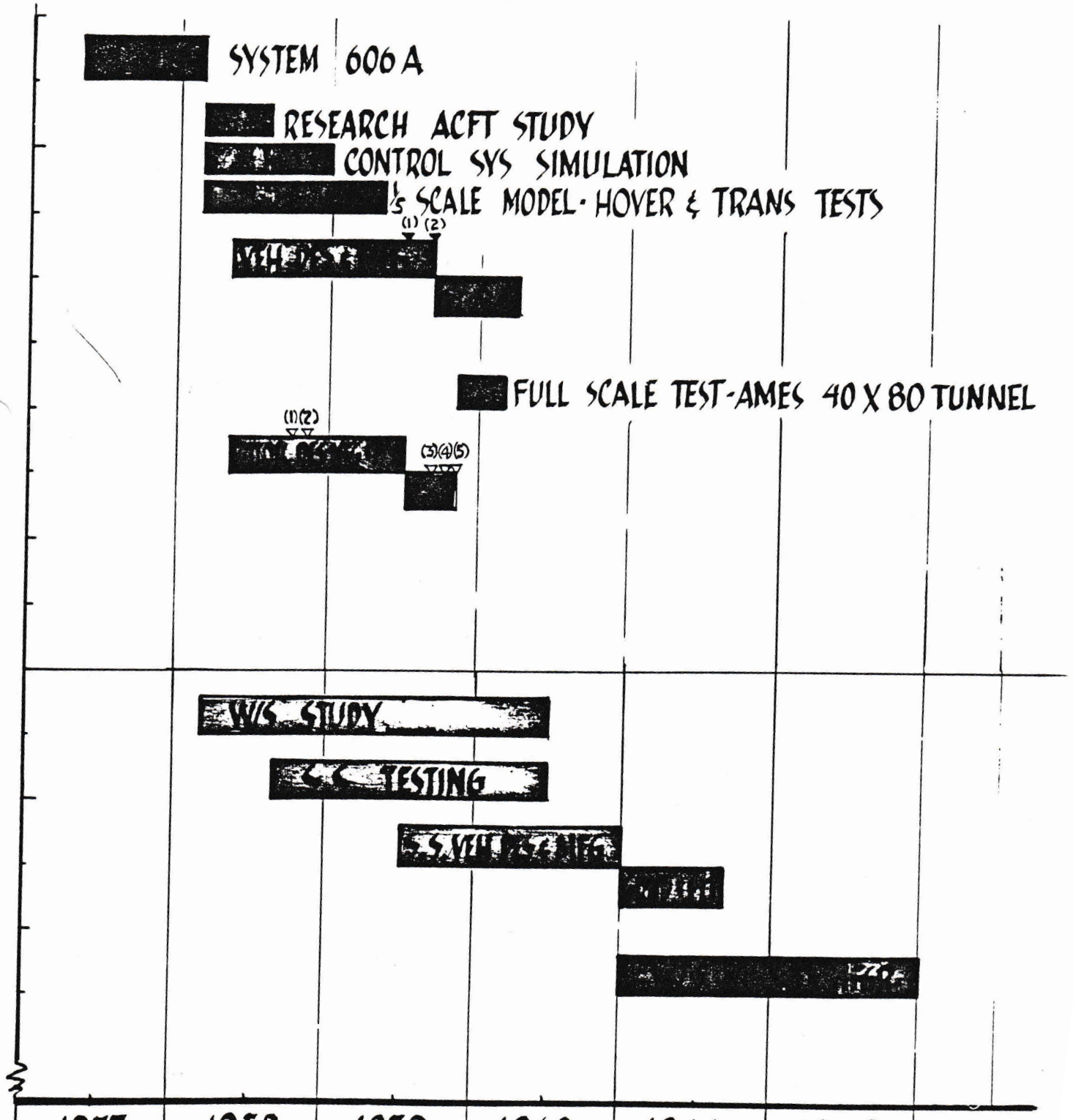
DESIGN AND FABRICATE ONE AIRCRAFT
CONSTRUCT ENGINE TEST STAND

WIND TUNNEL TESTS
SYSTEM ANALYSIS
GFAE
PROPULSION DEVELOPMENT

ECOMMENDED FY FUNDING
(000 OMITTED)

	'58	'59	'60	'61	'62
AF					
PERSONIC TESTING, ST RG W/S STUDY	0	(600)	-	-	-
S. MFGR & TEST MODIF. IROCAR VEH.		800	500		
ES. OF S.S. PROTOTYPE			1,000	10,000	15,000
TOTAL	2600	0	800	1,500	10,000	15,000
	(FY 54 & 57)		1.4		
; ARMY					
VROCAR DEV., MFG.	2.028	900			
RND & FLT TEST		800			
UND TRFR 606A		600			
; FAE		500			
V/T FACILITY		35			
TOTAL	2.028	2.835			

[illegible] INTEGRATED [illegible] PROGRAM



USAF [illegible]

14

COMMENDED INTEGRATED PROGRAM

❶ REDIRECT 606A IMMEDIATELY TO:
- STUDY SIMPLIFIED VEHICLE
- CONDUCT 1/5 SCALE AVRO CAR WT TESTS
- CONDUCT CONTROL SYST COMPUTER STUDY
- CONTINUE GENERALIZED S/S W/S STUDIES

❷ PROGRAM FUTURE FUNDS TO:
- CONTINUE S.S. DEVELOPMENT TESTS
- OPERATE TEST RIG (MAKE REPAIRS, IF DESIRABLE, AT EXPENSE OF OTHER SCHEDULED TESTS)
- IMPLEMENT DEVMT OF AF TYPE VEHICLE

❶ PROCURE REMAINDER OF MINIMUM PROGRAM WITH PRESENT MIPR

❷ PROGRAM FUTURE FUNDS TO:
PROCURE SECOND AVRO CAR & COMPLETE TEST PRGM

POSSIBLE APPROACHES

SAF FUND PV-704 TYPE VEHICLE X
- EST $ 6.0 MILLION FOR 1 VEHICLE
- 2 YEARS TO COMPLETE
- CHANGED CONTRACTOR INTEREST

BOTH AVRO CAP & PV-704 PROCURED X
- TWO DEVELOPMENTS EXPENSIVE
- DILUTE CONTRACTORS EFFORT

INTEG. USAF/ARMY PROG. ✓
- MEET ALL ARMY REQ'MTS
- FIRST STEP FOR USAF VEHICLE
- REASONABLE COST TO D.O.D.

)ATA FROM AVRO CAR

	ARMY	USAF	
VER	✓	✓	
ANSITION	✓	✓	
AB. & CONTROL	✓	✓	X
LET	✓	X	
ITERNAL AIRFLOW	✓	X	✓
OMBUSTION	—	X	

AVROCAR

SUMMARY

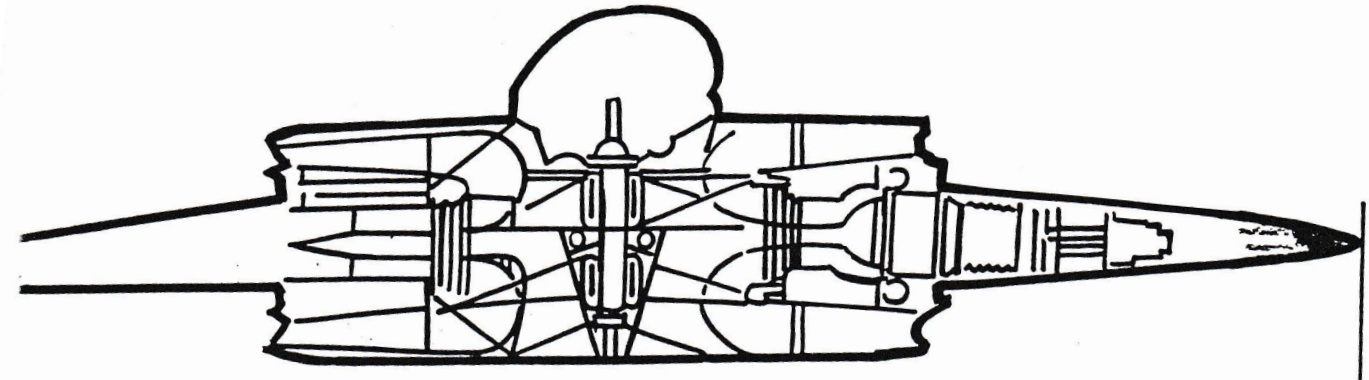
ESIGN SIMPLER THAN PV 704, BUT STILL
IGH RISK PROGRAM

UCCESS DEPENDENT UPON SOLUTION OF
ROBLEM AREAS

- STAB & CONTROL
- PROPULSION SYS EFFICIENCY
- WEIGHT
- GROUND EFFECT CHARACTERISTICS
- COMBINATION OF THESE PROBLEMS

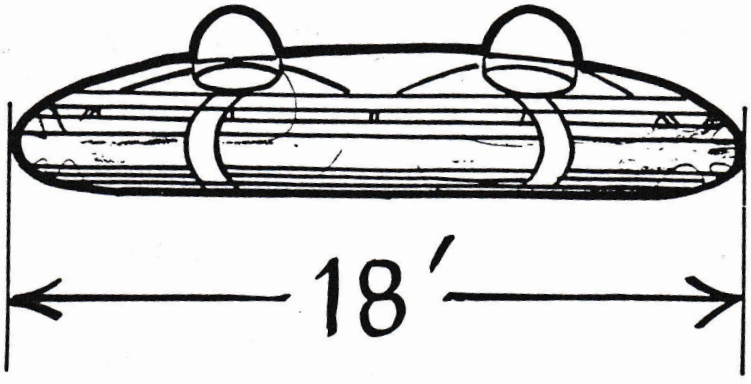
AVROCAR MUST BE CONSIDERED A RESEARCH VEHICLE

HICLE COMPARISON



35′

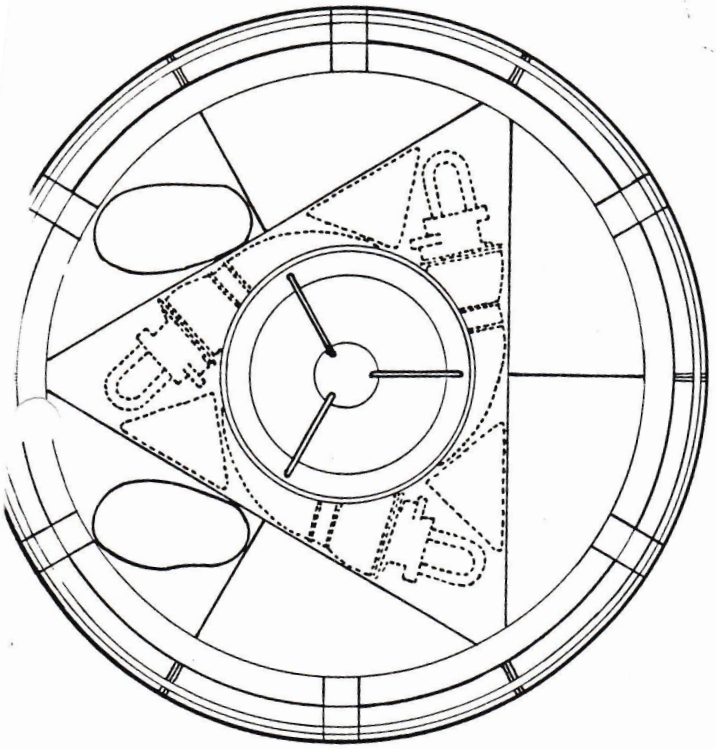
PV-[illegible]

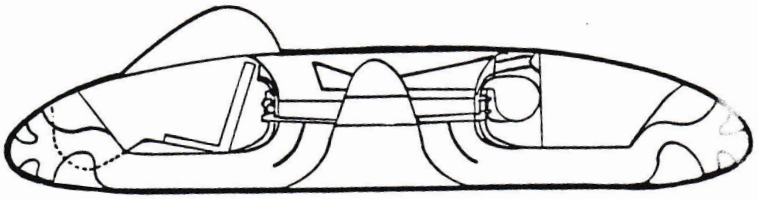


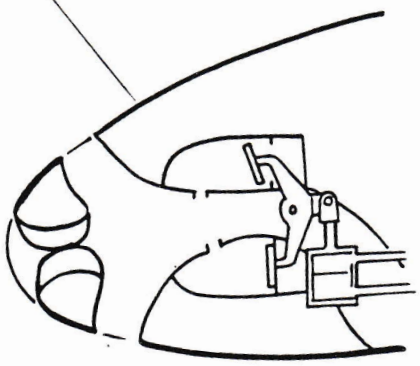
18′

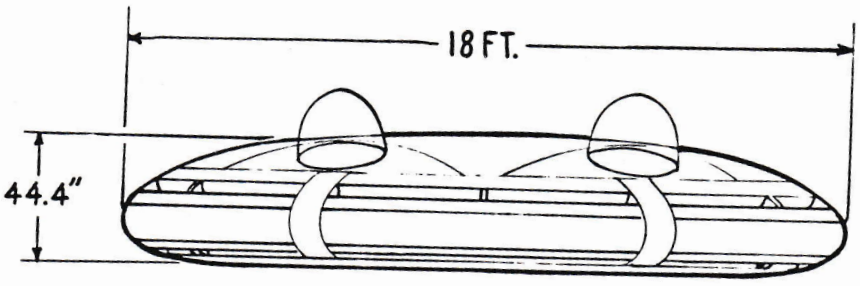
AVRO CAR

AVRO CAR









REASON FOR CHANGE

ARMY INTEREST IN AVRO CAR

AVRO FUNDS FOR PV 704 REDUCED

DOD DESIRE FOR INTEGRATED AIR FORCE - ARMY PROGRAM

USE OF AVRO CAR TO TEST NEW PROPULSION SYSTEM

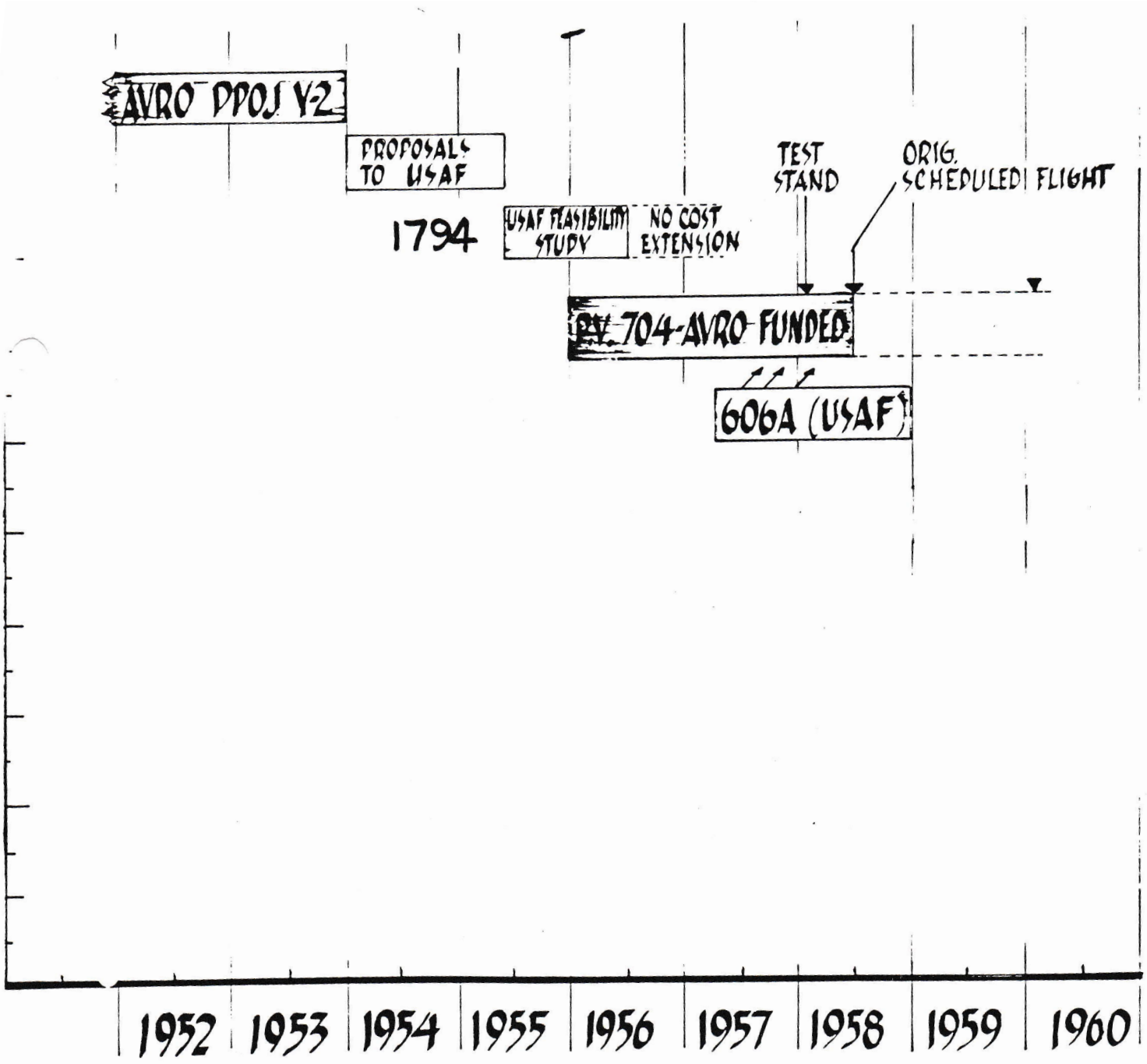
USAF DESIRE TO CONFIRM BASIC VTOL & TRANSITION AT EARLIEST DATE

CURRENT SITUATION

PROGRAM REORIENTATION IN PROGRESS

- SAME BASIC CONCEPT
- SMALLER, SIMPLER VEHICLE
- DEMONSTRATES BASIC CONCEPT
- POSTPONES DEVELOPMENT WITH SUPERSONIC PERFORMANCE

UNCLASSIFIED



JOINT EFFORT PROGRAM

PV-704 EFFORT

DESIGN AND FABRICATE ONE AIRCRAFT
CONSTRUCT ENGINE TEST STAND

PROGRAM AUGMENTS PV-704 EFFORT

WIND TUNNEL TESTS
SYSTEM ANALYSIS
GFAE
PROPULSION DEVELOPMENT

DESIGN CONCEPT

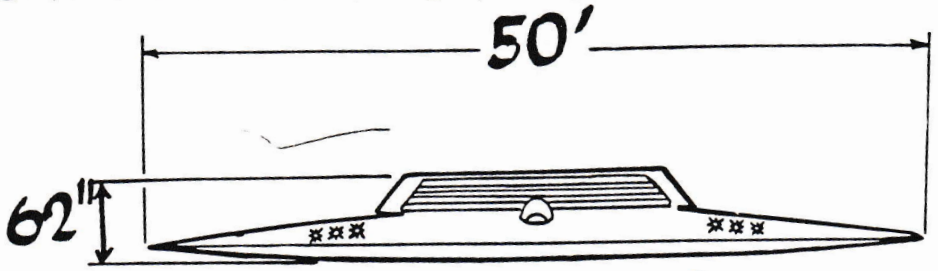
COMBINES:

VTOL/STOL WITH HIGH ALTITUDE, HIGH SPEED PERFORMANCE.

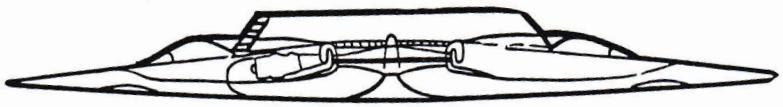
FEATURES:

INTEGRATED AIRFRAME - PROPULSION SYSTEM - MANUFACTURING SIMPLICITY.

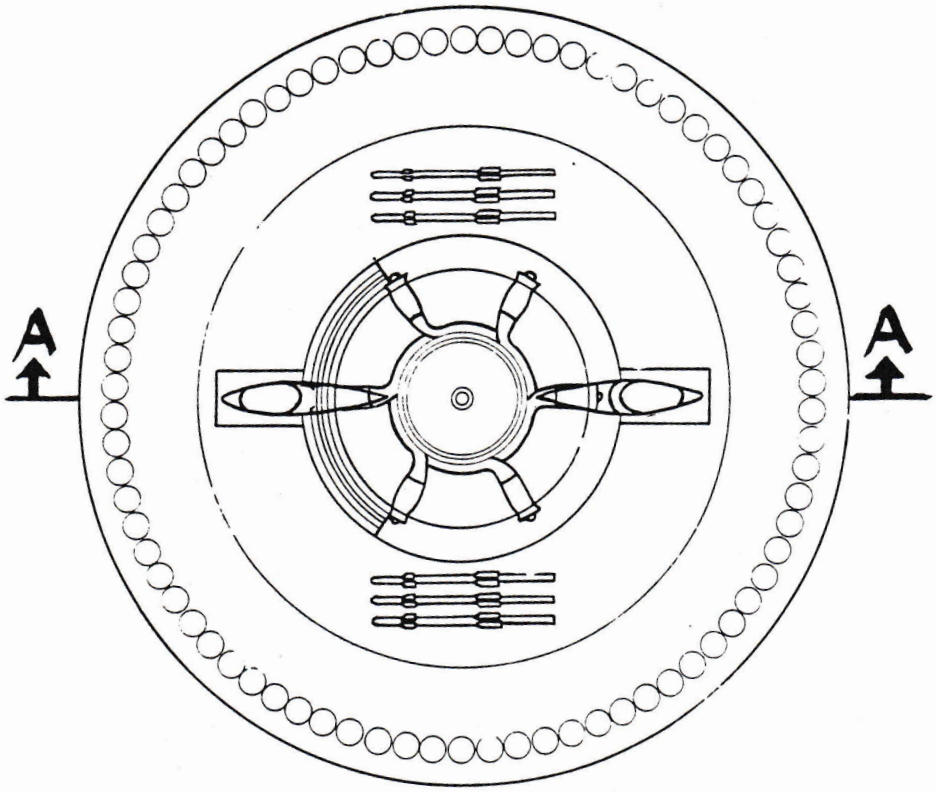
NERAL ARRANGEMENT
DIA. FIGHTER BOMBER



FORWARD VIEW



SECTION A-A

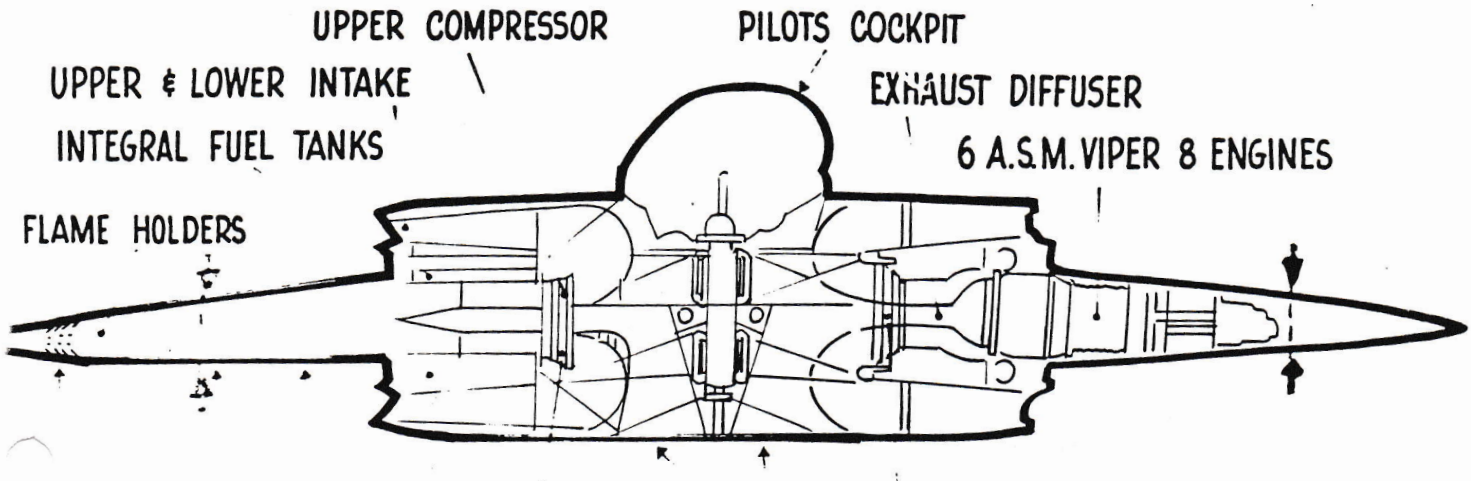


PLAN VIEW

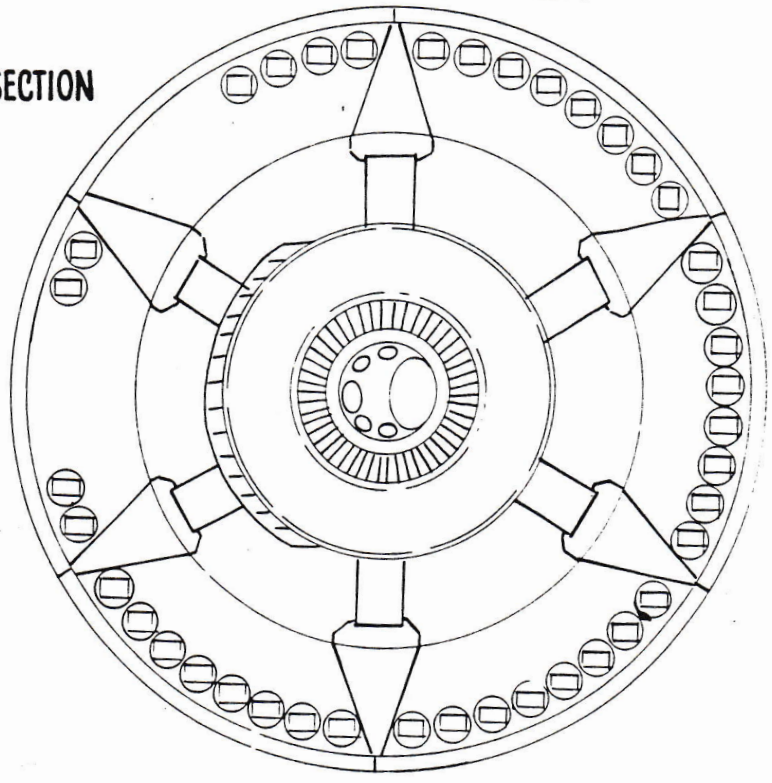
SECRET

UNCLASSIFIED

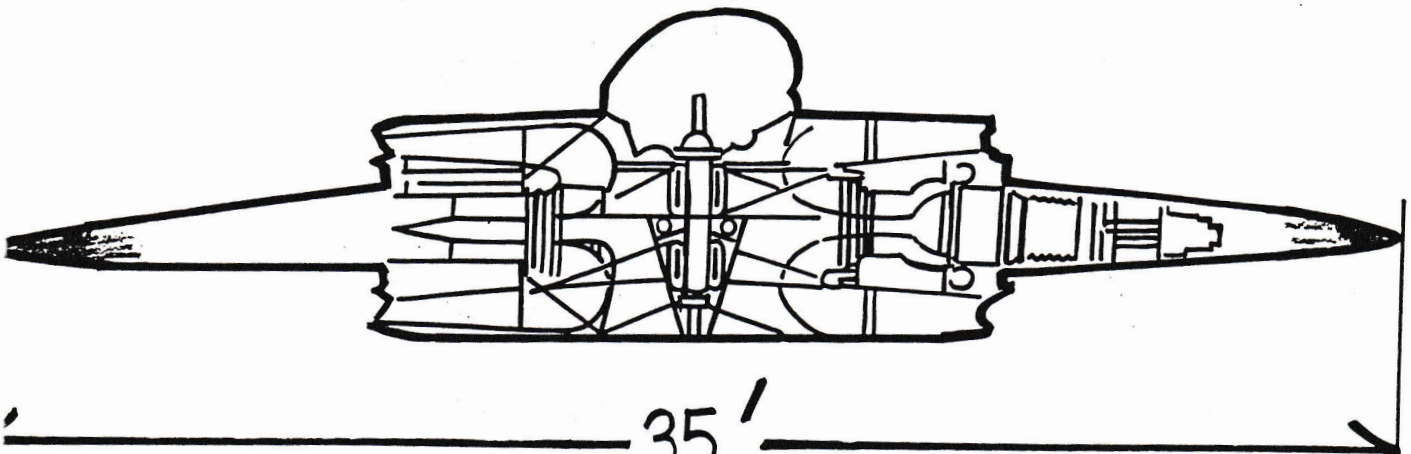
AVRO PU704 VEHICLE



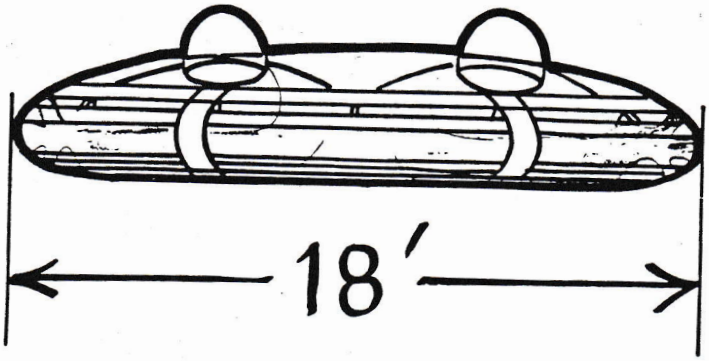
T CONTROL
HUTTERS
LOWER COMPRESSOR
TURBINE
TURBINE EXHAUST
OUTER WING
NER WING DIFFUSER SECTION



VEHICLE COMPARISON



PV-70A

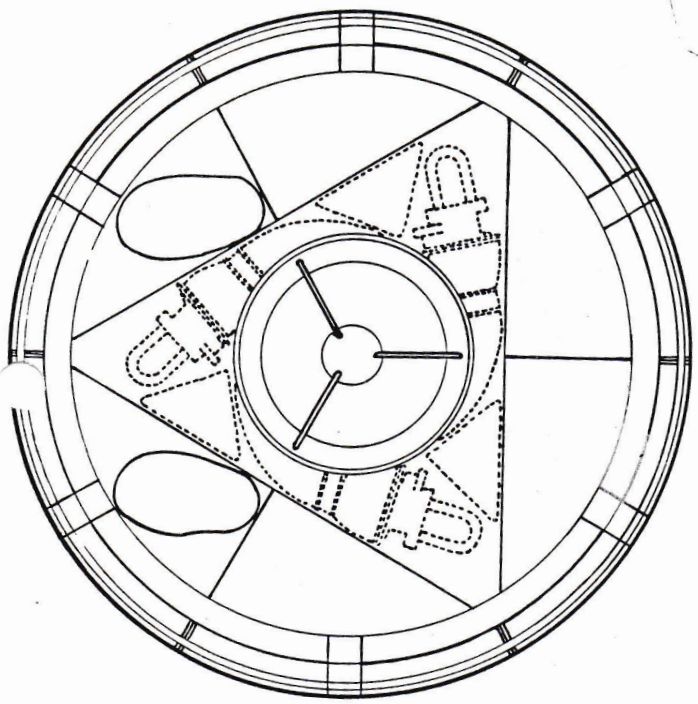


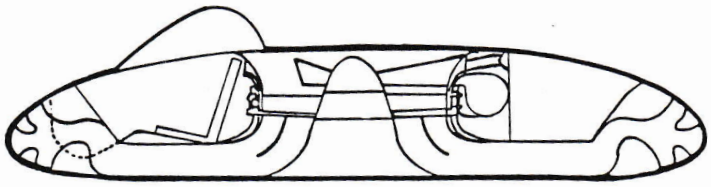
AVRO CAR

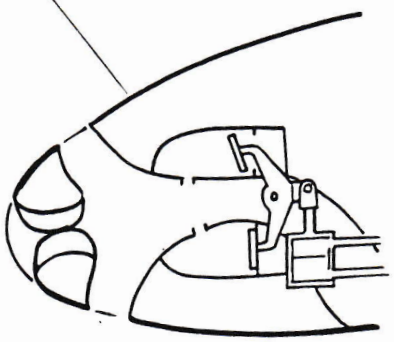
UNCLASSIFIED

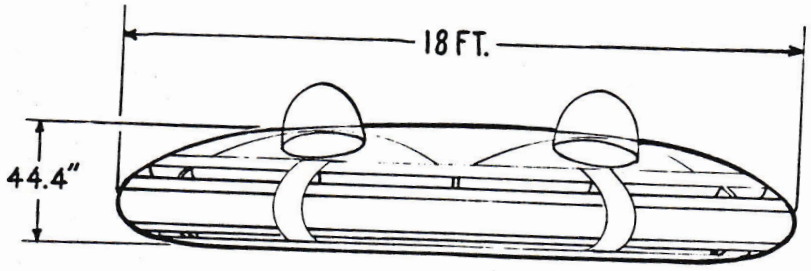
~~SECRET~~

AVRO CAR









UNCLASSIFIED

~~SECRET~~

REASON FOR CHANGE

- ARMY INTEREST IN AVRO CAR
- AVRO FUNDS FOR PV 704 REDUCED
- DOD DESIRE FOR INTEGRATED AIR FORCE - ARMY PROGRAM
- USE OF AVRO CAR TO TEST NEW PROPULSION SYSTEM
- USAF DESIRE TO CONFIRM BASIC VTOL & TRANSITION AT EARLIEST DATE

CURRENT SITUATION

PROGRAM REORIENTATION IN PROGRESS

- SAME BASIC CONCEPT
- SMALLER, SIMPLER VEHICLE
- DEMONSTRATES BASIC CONCEPT
- POSTPONES DEVELOPMENT WITH SUPERSONIC PERFORMANCE

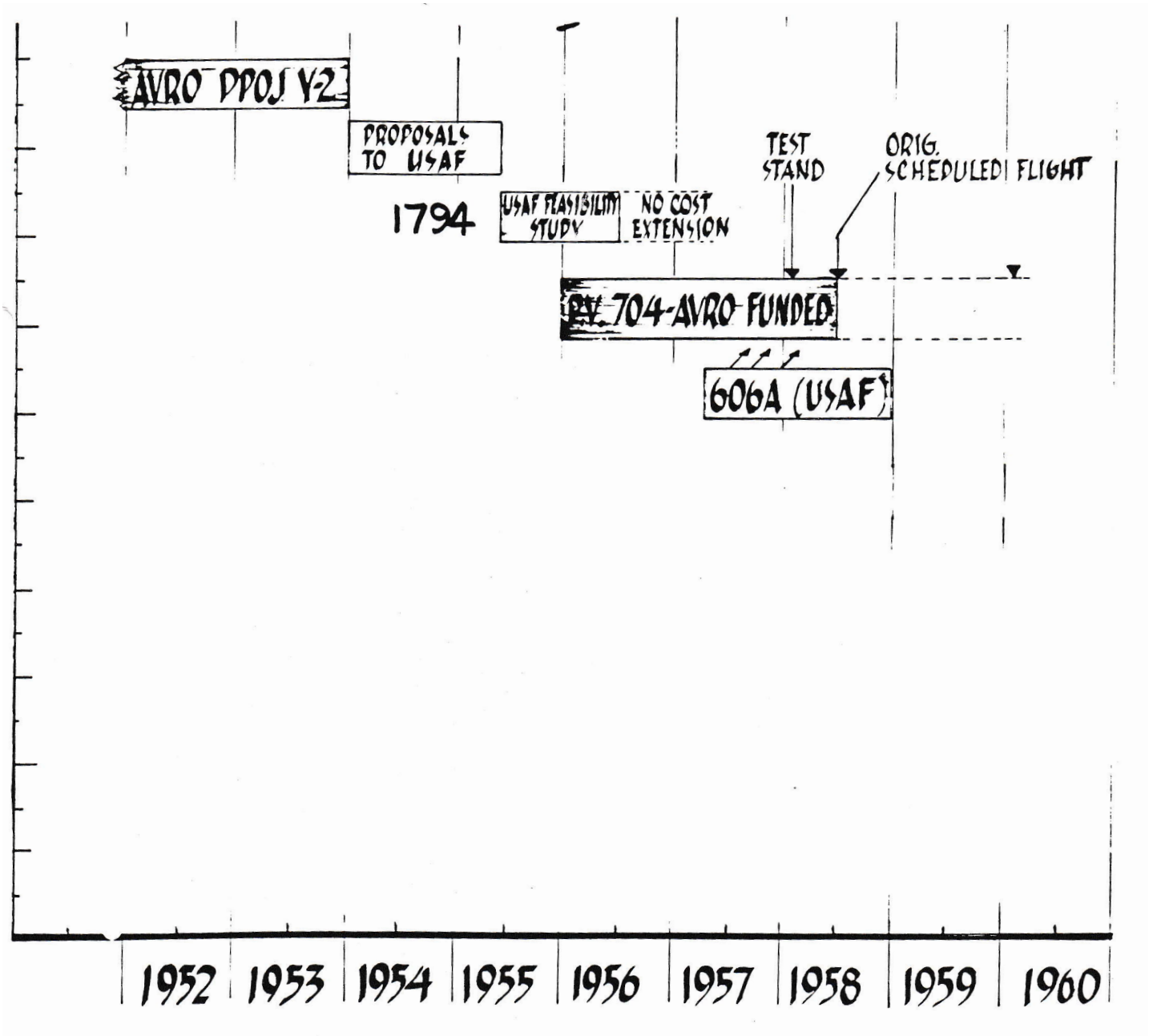
FUNDING HISTORY

..OF AVRO CONCEPT

CANADIAN GOVT-(1952-53)	300,000
AVRO (THRU 1 MAR 58)	2,500,000
USAF (FY-54)	785,000
USAF (FY-57)	1,815,000
	2.6

TOTAL $5,500,000

UNCLASSIFIED



JOINT EFFORT PROGRAM

AVRO PV-704 EFFORT

- DESIGN AND FABRICATE ONE AIRCRAFT
- CONSTRUCT ENGINE TEST STAND

USAF PROGRAM AUGMENTS PV-704 EFFORT

- WIND TUNNEL TESTS
- SYSTEM ANALYSIS
- GFAE
- PROPULSION DEVELOPMENT

DESIGN CONCEPT

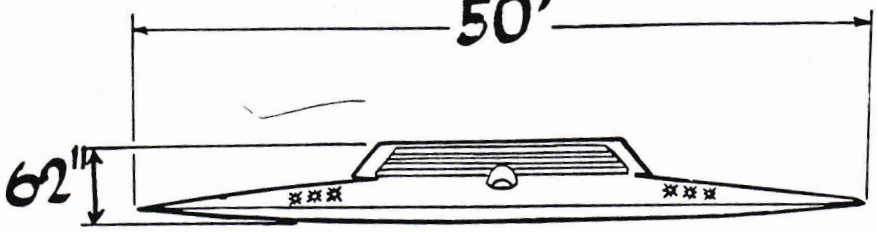
COMBINES:

VTOL/STOL WITH HIGH ALTITUDE, HIGH SPEED PERFORMANCE.

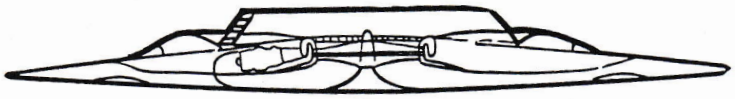
FEATURES:

INTEGRATED AIRFRAME - PROPULSION SYSTEM - MANUFACTURING SIMPLICITY.

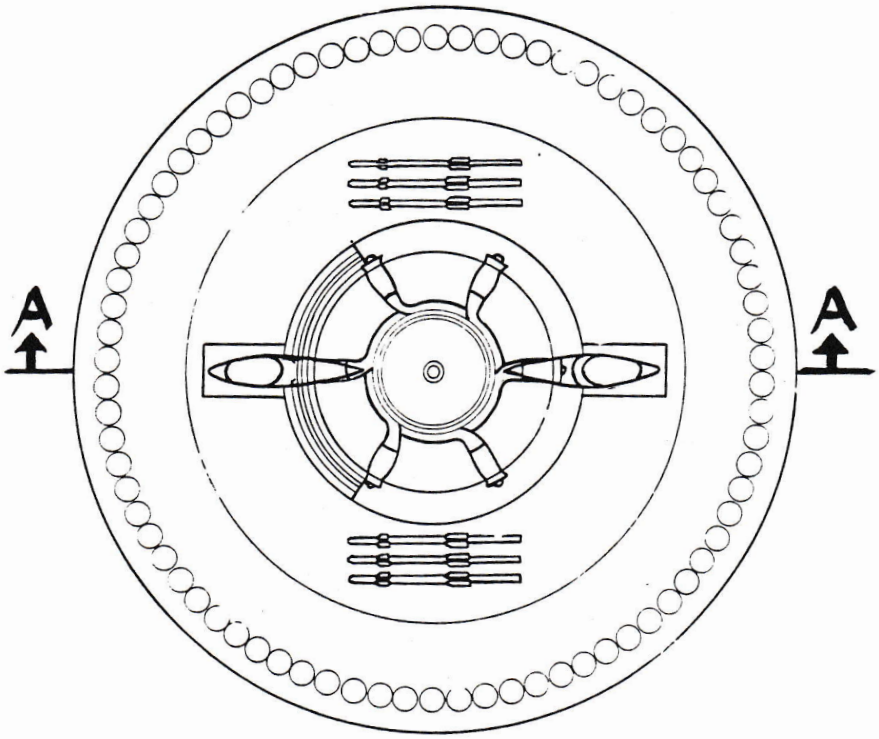
GENERAL ARRANGEMENT 50' DIA. FIGHTER BOMBER



FORWARD VIEW

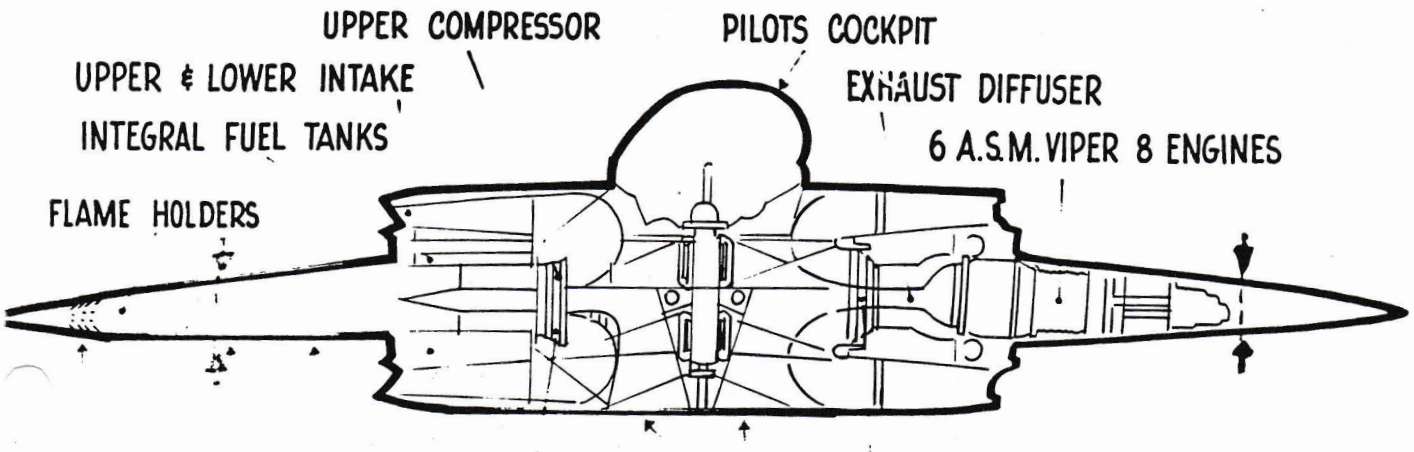


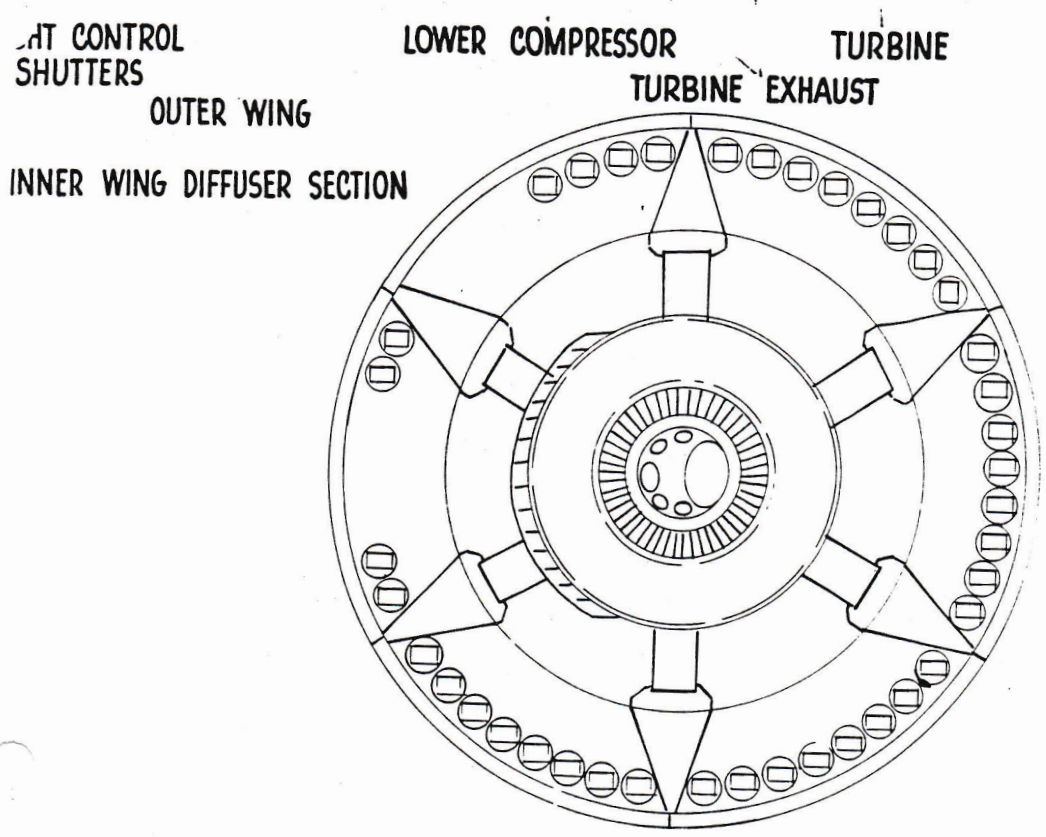
SECTION A-A



PLAN VIEW

AVRO PU704 VEHICLE





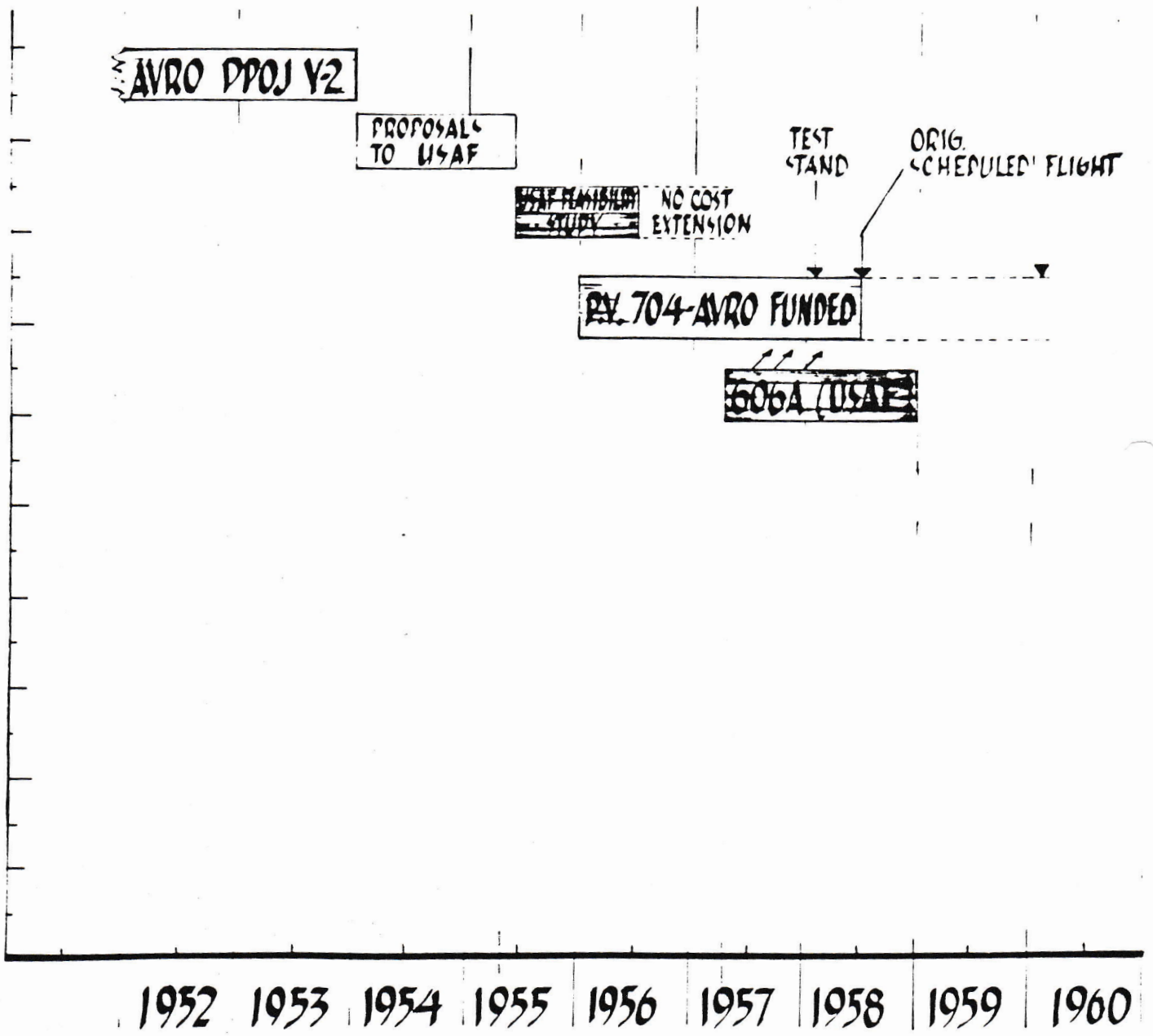
ESTIMATED PERFORMANCE

	CURRENT DESIGN (PV704)		NEW DESIGN
	INITIAL	MODIFIED	
MAX SPEED	M 0.48	M 1.74	M 3.0
CEILING	25,000'	85,000'	94,000'
RANGE	400 N.MI.	700 N.MI.	980 N.MI.
CRUISE	M 0.45 @ 20,000'	M 1.7 @ 80,000'	M 2.2 @ 90,000'

SYSTEM 606A

~~SECRET~~ UNCLASSIFIED

TIME HISTORY
AVRO VTOL PROGRAM



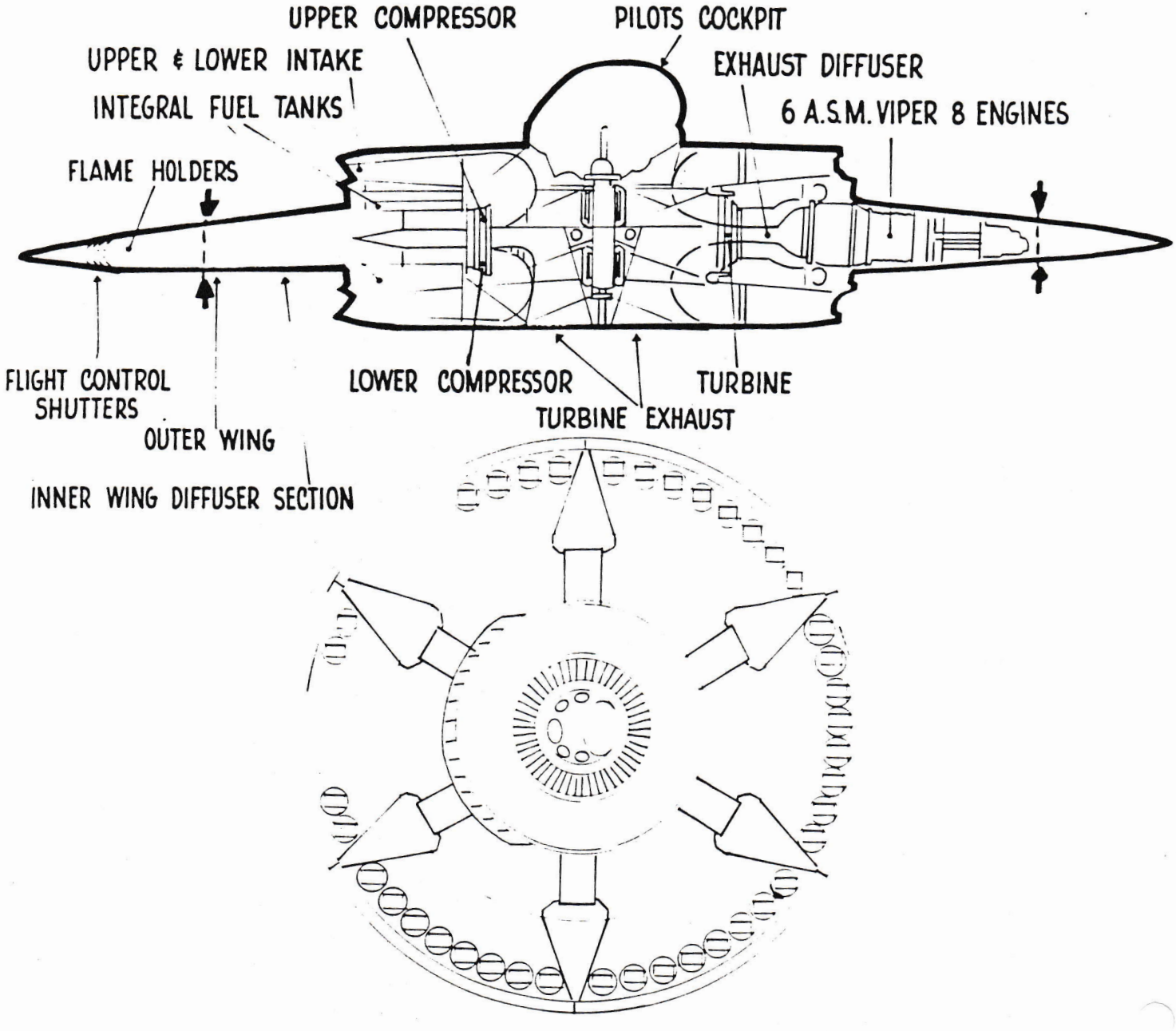
~~SECRET~~ UNCLASSIFIED

FUNDING HISTORY

...OF AVRO CONCEPT

	$400,000 -
CANADIAN GOVT-(1952-53)	300,000
AVRO (THRU 1 MCH 58)	2,500,000
USAF (FY-54)	785,000
USAF (FY-57)	1,815,000
TOTAL	5,500,000

AVRO PU704 VEHICLE



UNCLASSIFIED

6 VIPER TEST RIG

TS:

TEST RIG EXISTS

REPRESENTS LARGE INVESTMENT.

'RO STATES:

FIRST LARGE TURBO DRIVEN FAN

TEST DATA GENERALLY APPLICABLE

WILL NOT CONTINUE TO FUND

WANT USAF SUPPORT FOR EITHER:

6 MOS OPERATING COST (100,000)

SPARES + OPERATING COST (10,000)

USAF COMMENTS:

CONT. RUNNING- SOME DATA APPLICABLE

COMPARE DIFFERENT COMPRESSORS

DON'T STOCK SPARE PARTS

RECOMMEND:

SUPPORT OPERATION ONLY

INDIV. NEGOTATION FOR FAILED PARTS

REORIENT TESTS TO GENERALIZED DATA

UNCLASSIFIED

Evaluation

OF AVRO CAR PROPOSAL

TECHNICAL PROPOSAL

EVALUATION BASED ON:

MODEL SPECIFICATION DESCRIBING
AVROCAR

WORK ITEMS LISTED IN PROPOSAL LETTERS

500 HR TURBO ROTOR DEVELOP.
ENGR MOCKUP
500 HR W.T. PROGRAM
CONTROL SYST. COMPUTER STUDY & TEST
FULL SCALE WING SECTION
LIMITED FREEDOM MODEL
GROUND & FLIGHT TESTS
FULL SCALE VEHICLE TEST IN AMES TUNNEL

PROPOSAL CONDITIONS

PROPOSAL LETTER:

FIXED PRICE "OFF THE SHELF" PROGRAM.

DESIGN TO MEET AVRO SPECIFICATION
STD MIL SPECS & HIAD AT AVROS OPTION

U.S. GOVT NOT TO HAVE ROYALTY FREE
LICENSE RIGHTS

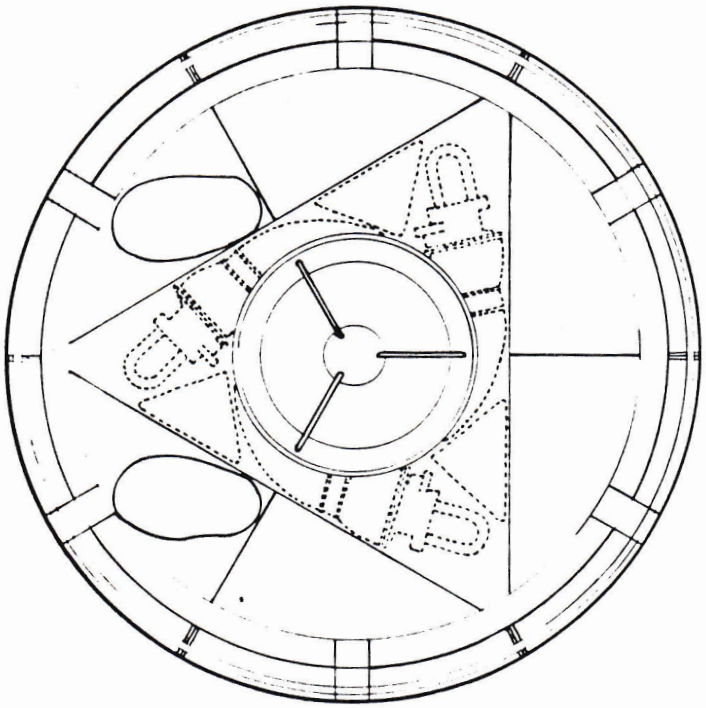
SUBSEQUIENT ORAL STATEMENT BY AVRO:

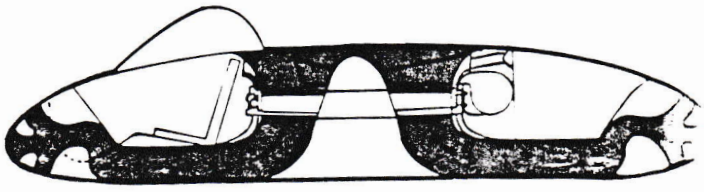
PERF GUARANTEES

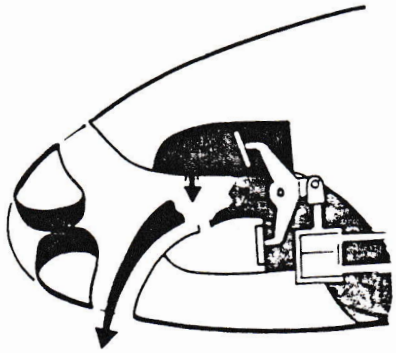
- ○ *HOVER & TRANS.* ○ *10 MINUTES*
- ● *FORWARD SPEED* ○ *50 KNOTS*

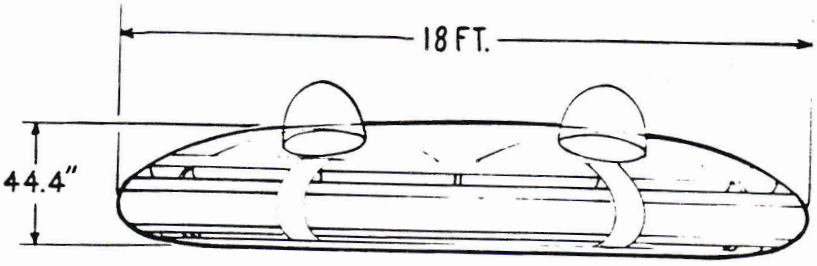
BASIC CONTRACT TO INCLUDE OPTION
FOR GRND & FLIGHT TEST PROGRAM.

AVRO CAR

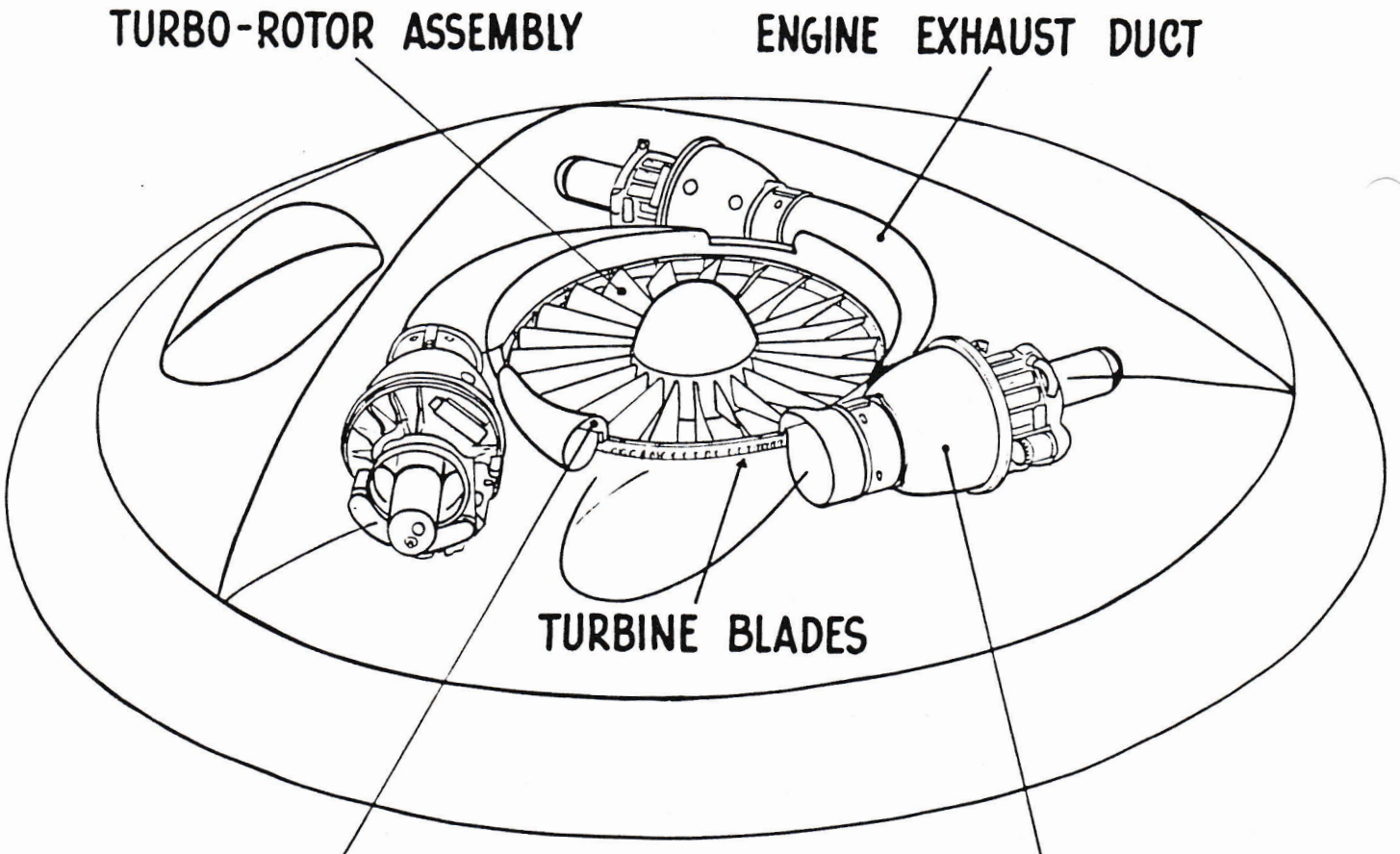








ENGINE INSTALLATION



UNCLASSIFIED

TECHNICAL EVALUATION

PROPULSION

TIP TURBINE POWERED FAN NEW & UNPROVEN

PRINCIPLE SOUND-MAY HAVE PROBLEMS DUE:

- *PARTIAL ENTRY TURBINE LOSSES*
- *DUCT LOSSES*

PRESSURE DISTRIBUTION MAY BE CRITICAL FOR:

- *TURBINE FAN*
- *J-69 COMPRESSOR*

DESIGN CONCEPT

VTOL / STOL WITH HIGH ALTITUDE, HIGH SPEED PERFORMANCE.

INTEGRATED AIRFRAME - PROPULSION SYSTEM - MANUFACTURING SIMPLICITY.

STATEMENT OF PROBLEM

ARMY & HQ USAF HAVE INDICATED DESIRE TO COMMIT FUNDS FOR FLYING RESEARCH VEHICLE

DOD REQUESTED USAF TO EVALUATE AVRO PROPOSALS & RECOMMEND INTEGRATED USAF/ARMY PROGRAM

PV-704 PROGRAM BEING STOPPED. USAF SYSTEM 606A MUST BE REORIENTED