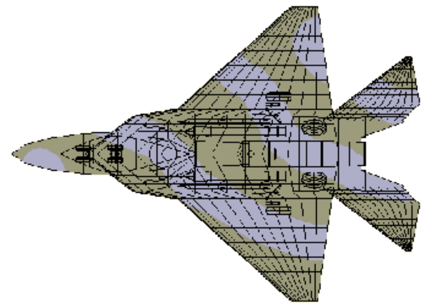
Design of Jet STOVL Aircraft using RDS-Professional



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ABSTRACT

This paper describes the technical analysis of a notional fighter design developed to assess the concept of combining traditional catapult launch with a vertical landing on the aircraft carrier. This work was done in support of a companion paper by the same authors, entitled "Breaking the Paradigms: *Catapulting* STOVL" (1) being presented in the same session at IPLC. All design and analysis work was done using the RDS-Professional design software, a product of Conceptual Research Corporation.

INTRODUCTION

The technical means to be employed for getting a carrier-based aircraft on and off the boat has a large impact on aircraft weight, cost, and operational effectiveness. The use of a catapult for takeoff and an arresting wire for landing (CAT-TRAP) is the traditional solution, and offers high launch weight and reasonable bring-back weight, is well understood and integrated into current fleet operations and hardware assets, and presents a reasonable and well-understood set of design penalties to the aircraft designer. Recent studies including those described in ref. (2) point to an alternative - using the catapult for launch, but using aircraft vertical landing capabilities for at-sea recovery (CAT-VL). This may offer design weight penalties no worse than the CAT-TRAP option, and with enhanced operability and safety. Perhaps even more importantly, it may substantially increase commonality in a multi-service design.

This paper describes the development and analysis of a notional future multirole fighter with optional vertical land capability, developed to be used as a tool for assessment of the CAT-VL concept. That assessment, and a discussion of the implications and benefits of CAT-VL, is contained in the companion paper (1).

Design work was done starting with the notional design concept previously developed by the lead author in the 1994-1995 time frame and publicly reported in references (2) and (3). This concept is shown in fig.1, and was used at that time as a point of departure for a variety of trade studies on missions, roles, technologies, and multi-service commonality strategies as reported.

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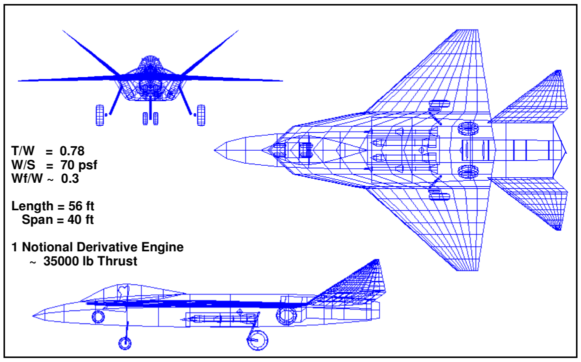

Figure 1. Design Concept from Ref. (2)

The Air Force version of this design had an empty weight of 25, 505 lb., and a design takeoff weight of 41, 245 lb. It was powered by a notional advanced fighter engine of about 35,000 pounds of thrust, with a wing area of 590 sq. ft.

This notional design concept was then revised to better reflect current thinking. Based on information in ref. (4), the vertical lift concept was changed from the Lift-Plus-Lift/Cruise to the Shaft-Driven Lift Fan (SDLF). The engine was moved forward to allow incorporation of the type of vectoring nozzle used on the YAK-141. This required a revision to the tail arrangement, wherein the V-tails were mounted on boom-like structures alongside and aft of the engine. These changes resulted in a configuration as shown in Figure 2.

The design requirements from the prior study (refs. 3 & 3) were retained for this study, as follows:

- 550 n.mi.radius, high-medium-medium-high flight profile
- internal carriage of two 1000lb. JDAMs, two AIM-120Cs, gun and ammo
- 7.33 g load factor at mid-mission fuel weight
- 3.5 g sustained turn rate at .9 M and 30,000 feet
- 4000 foot takeoff and landing.

Design layout and analysis work was done using done using the RDS-Professional design software, a product of Conceptual Research Corporation (5,6). Based on the methods in the AIAA textbook `Aircraft Design: A Conceptual Approach' (7), RDS features a 3-D CAD module for design layout, and has analysis modules for aerodynamics, weights, propulsion, and cost. RDS includes capabilities for aircraft sizing, mission analysis, and performance analysis including takeoff, landing, rate of climb, Ps, fs, turn rate, and acceleration. RDS also provides graphical output for drag polars, L/D ratio, thrust curves, flight envelope, and range parameter, and features both traditional carpet plot optimization and a multivariable design optimizer. Comparative studies indicate that RDS-Professional produces results within the usual accuracy for conceptual design efforts.

Aerodynamics analysis included subsonic parasite drag, estimated by the component buildup method. Supersonic wave drag was determined by the equivalent Sears-Haack technique. Transonic drag was determined by empirical methods. Drag due to lift was calculated by the leading-edge suction method using a calculated Cl-alpha based upon DATCOM methods. Maximum lift was estimated using DATCOM charts. Figures (3) through (6) show aerodynamic results.

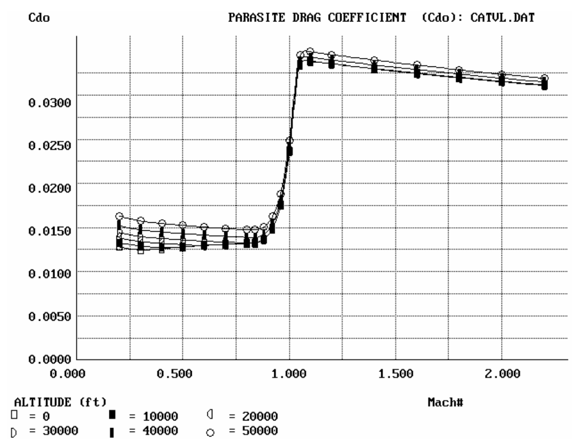

Fig. 3. Parasitic Drag

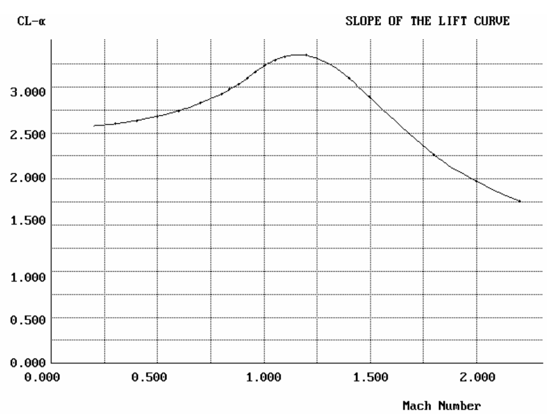

Fig. 4. CL-alpha vs. Mach

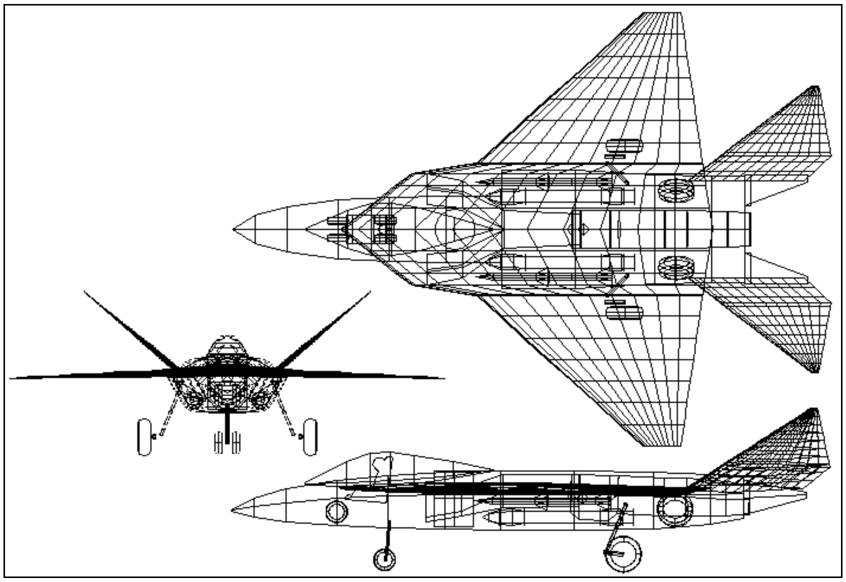

Figure 2. Revised Notional Design Concept

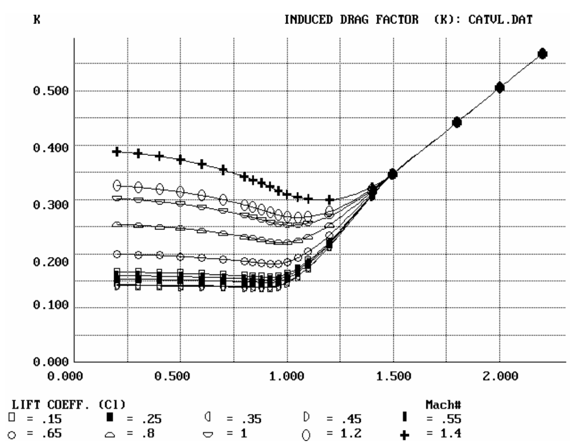

Fig. 5. Drag-due-to-Lift Factor (K)

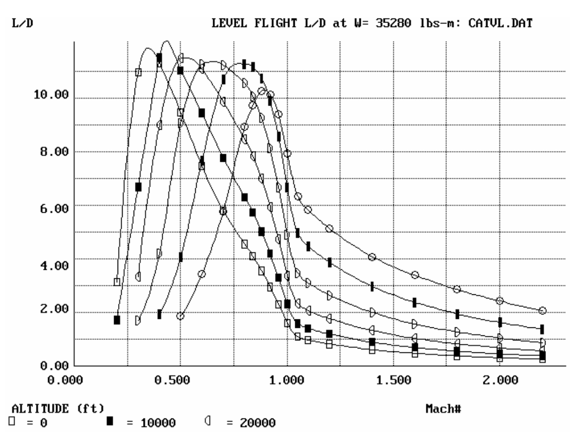

Fig. 6. Lift-to-Drag Ratio in Level Flight

Weights and balance were estimated statistically using equations from chapter 15 of reference 7. Weights were adjusted based on application of composites and other advanced materials, and weight increments were estimated for use of internal weapons bays, stealth treatments, and additional equipment such as an APU. Weights adjustments for the use of a catapult launch and vertical land were made including weight estimates for the shaft-driven lift fan system (table 1). Summary weights result are shown as Table (2).

Table 1. Miscellaneous empty weight breakdown

APU	300
Wep bay	1500
Stealth	1000
Lift fan	2000
Doors/nozzle	300
Main nozzle	400
Stovl controls	200
Fuselage cutout	250
Total STOVL	5950
Add cat struct.	500
Total CATVL	6450

Table 1. CAT-VL Weights Est.

STRUCTURES GROUP	10392
Wing	3252.3
Vert. Tail	866.5
Fuselage	4627.6
Main Lndg Gear	775.1
Nose Lndg Gear	318.1
Engine Mounts	63.3
Firewall	113.0
Engine Section	53.3
Air Induction	322.9
PROPULSION GROUP	6355
Engine(s)	4930.0
Engine Cooling	273.0
Oil Cooling	37.8
Engine Controls	21.2
Starter	66.4
Fuel System	1027.0
EQUIPMENT GROUP	4921
Flight Controls	1020.8
Instruments	128.8
Hydraulics	171.7
Electrical	706.5
Avionics	1945.4
Furnishings	391.7
Air Conditioning	536.0
Handling Gear	20.7
MISC EMPTY WEIGHT	6450
TOTAL WEIGHT EMPTY	28119.1
USEFUL LOAD GROUP	15981
Crew	220.0
Fuel	12850.9
Oil	50.0
Payload	2860.0
TAKEOFF GROSS WEIGHT	44100.0

(- Lift Fan and other STOVL gear included in Misc We allocation)*

Since the propulsion data used for the design studies of reference (2) was proprietary and is therefore unavailable to this study, a suitable engine data set had to be substituted. The Afterburning Turbofan of Appendice E of reference 7 had been defined with estimated year 2000 technologies and has a cycle and bypass ratio somewhat similar to current advanced engines. It was therefore used as representative, although not identical to likely engine data for such an advanced fighter.

Jet engine installation analysis was done including corrections for pressure recovery, bleed, inlet drag, and nozzle drag. Jet thrust and specific fuel consumption (SFC) for maximum afterburning and dry operations are shown in figures 7 through 10.

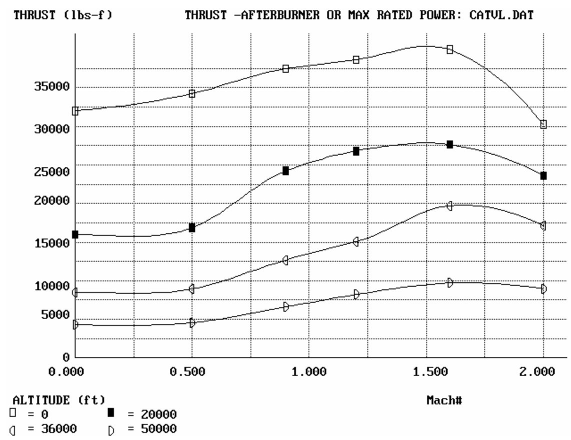

Fig. 7. Max. Afterburning Thrust

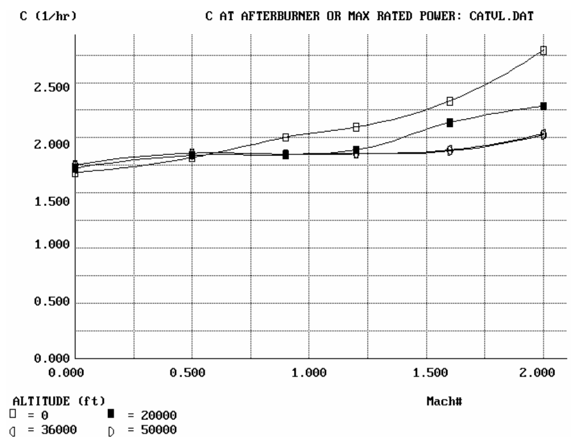

Fig. 8. Max AB. SFC

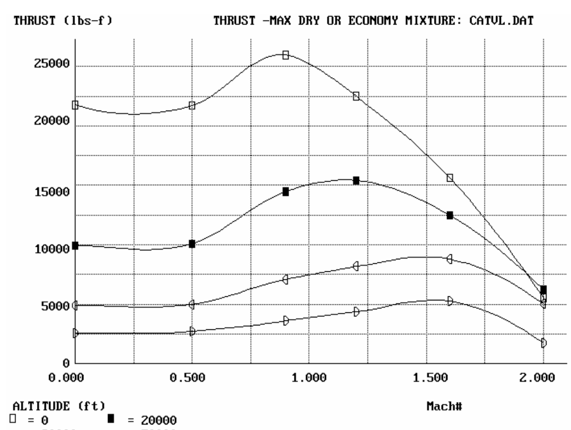

Fig. 9. Max Dry Thrust

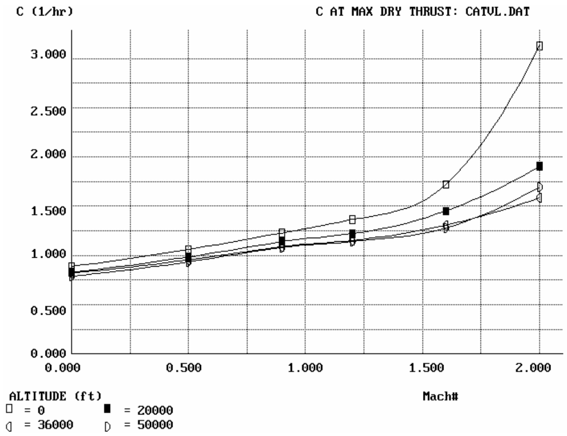

Fig. 10. SFC at Max. Dry Thrust

Performance analysis of this notional baseline design was done based on the calculated aerodynamics, weights, and performance. Sample results are shown in figures 11-13.

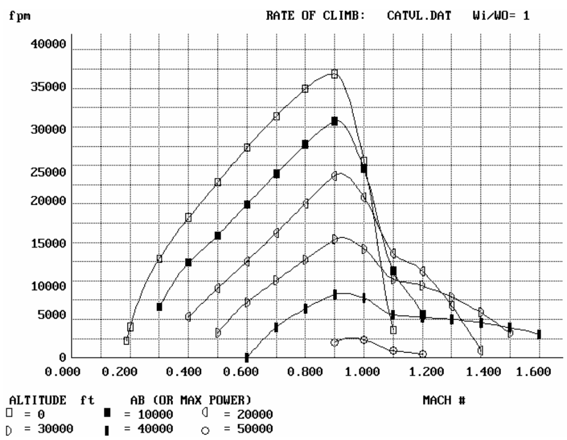

Fig 11. Rate of Climb

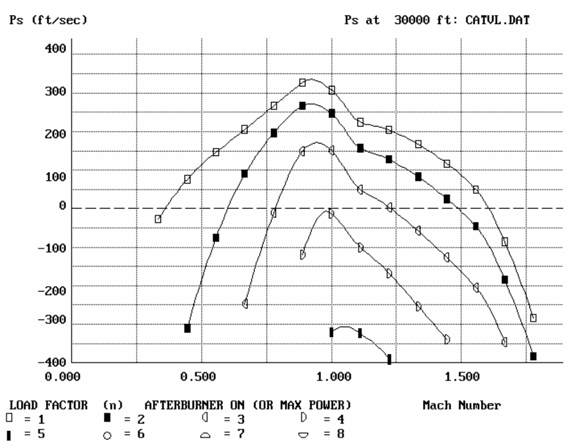

Fig. 12. Specific Excess Power (Ps) at 30,000 ft.

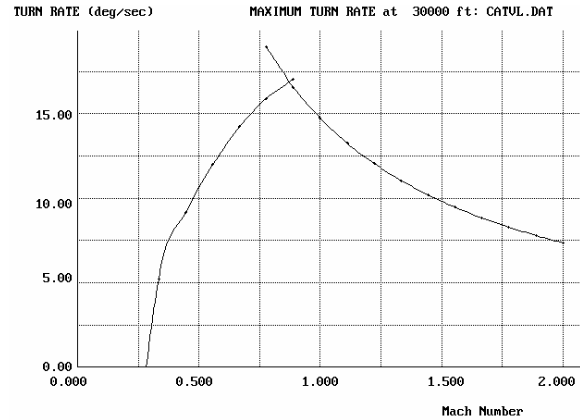

Fig. 13. Turn Rate at 30,000 ft.

Next, the notional designed was analyzed as to range over a typical high-medium-medium-high strike mission. Typical allowances for dash, combat, loiter, and recovery were included in the analysis. Figure 14 shows the change in aircraft weight and fuel weight during the mission, and table (3) details the range analysis results.

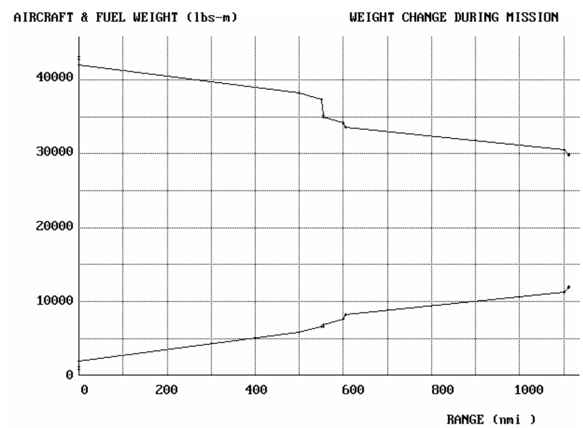

Fig. 14 CATVL Fuel Usage and Aircraft Weight

Table 3. CAT-VL Range Analysis

Seg. 5	CRUISE :	505.0 kts at	43000.0 ft	RANGE =	500.7 nmi
Seg. 6	CRUISE :	540.0 kts at	15000.0 ft	RANGE =	50.0 nmi
Seg. 9	CRUISE :	540.0 kts at	15000.0 ft	RANGE =	50.0 nmi
Seg. 11	CRUISE :	510.0 kts at	48000.0 ft	RANGE =	500.7 nmi
Seg. 12	LOITER :	210.0 kts at	200.0 ft	ENDURANCE =	0.2 hrs
TOTAL RANGE =		1101.4		TOTAL LOITER TIME =	0.17
FUEL WEIGHT =		12822.5		EMPTY WEIGHT =	28147.5
USEFUL LOAD (-Wf)=		3130.0		AIRCRAFT GROSS WEIGHT =	44100.0

A variety of range-related trade studies were performed to assess the design's sensitivity to changes in requirements, technologies, and design parameters. Several of these are shown in figures 15 and 16.

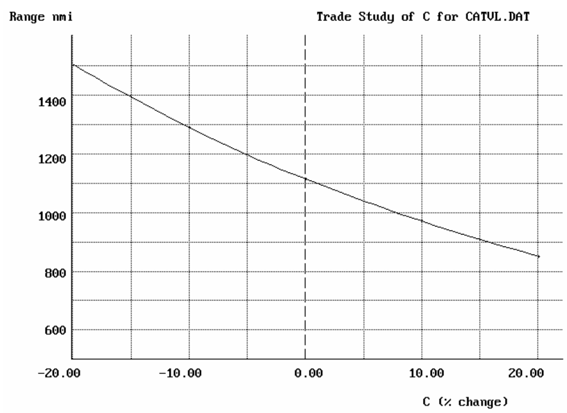

Fig. 15. Effect of SFC on Range

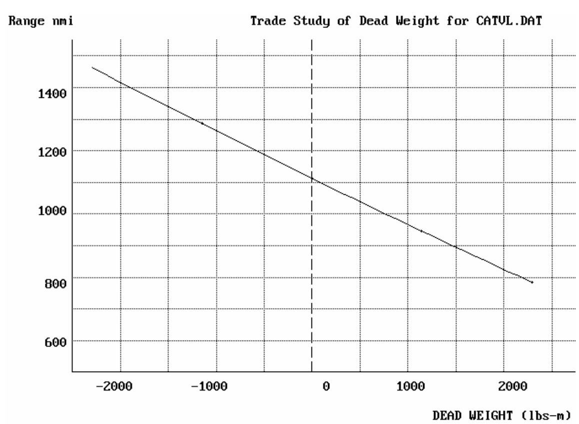

Fig. 16. Effect of Dead Weight on Range

SUMMARY & CONCLUSIONS

A notional design concept representative of an advanced single-engine strike fighter has been defined and analyzed as a tool for study of the potential for catapult-launch, vertical-land operation from aircraft carriers. This notional concept incorporates the Shaft-driven Lift Fan technology for vertical lift, and represents current design technology and thinking. The analysis indicates results representative of current fighter developments, and appears to validate this concept as a viable tool for study usage. The companion report (1) details the use of this notional concept in the assessment of the feasibility and desirability of CATVL as an operational and design concept.

REFERENCES

(1) McCrea, M., O'Brimski, F., Strickland, P., and Raymer, D., **Breaking the Paradigms: *Catapulting* STOVL,** International Powered Lift Conference, Oct. 2000

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(3). Raymer, D., "**Next-Generation Attack Fighter Conceptual Design Study**", Aircraft Design (Pergamon Press), Vol. 1 No. 1 March 1998

(4) **Jane's All the Worlds Aircraft**, 1999-2000, Jane's Information Group, London, 1999

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