AIAA-80-1862

Preliminary Design of a Very Advanced Technology Light Twin for the Mid-80's

J. Roskam, F. Grosveld, B. van Keppel, J. Eijsink and A.v.d. Hoeven, University of Kansas, Lawrence, Kan.

AIAA AIRCRAFT SYSTEMS MEETING

August 4-6, 1980/Anaheim, California

PRELIMINARY DESIGN OF A VERY ADVANCED TECHNOLOGY LIGHT TWIN FOR THE MID-80'S

J. Roskam†, F. Grosveld*, B. van Keppel*,
J. Eijsink*, A. v. d. Hoeven*
Flight Research Laboratory
University of Kansas
Lawrence, Kansas

Abstract

A preliminary design analysis was performed on a specification that called for a twin-engine business aircraft with performance nearing that of a jet airplane, coupled with the fuel efficiency of a turboprop. Use was made of advanced technologies in the areas of aerodynamics, propulsion, construction and stability and control. Results are presented which indicate a significant improvement in performance compared to turboprop airplanes currently in use.

Introduction

The VATLIT (Very Advanced Technology Light Twin) 1985 is a preliminary design of a light, twin-engine airplane for stage distances up to 2500 nautical miles.[1] The design aim was to study the feasibility of an executive turboprop twin of 5670 kg (12,500 lb) maximum takeoff weight with performance comparable to that of a jet airplane, combined with the fuel efficiency of a turboprop. Improvements have been found in the areas of aerodynamics, propulsion, structures and production methods[2] and are incorporated in the preliminary design. A high aspect ratio wing with a relatively high wing loading, supercritical airfoil sections that generate a high lift-to-drag ratio and winglets have been included to improve lifting surface characteristics. A separate surface stability augmentation system has been introduced into this design to improve the stability and control of the airplane at reasonable cost and weight without the redundancy penalties usually associated with such systems. Advanced structures and material properties (boron and carbon laminates) have been incorporated to keep the empty weight down. New production methods (metal bonding, synthetic material and foam techniques) have been considered. A study was made of the application of the propfan concept[3] to obtain a high efficiency at high cruise Mach number (.7) which will result in improved fuel efficiency. The design has been based on the FAA airworthiness requirements in the transport category (FAR, Part 25). Figure 1 depicts a three-view of the airplane, while Appendix A contains a summary of technical data of the airplane.

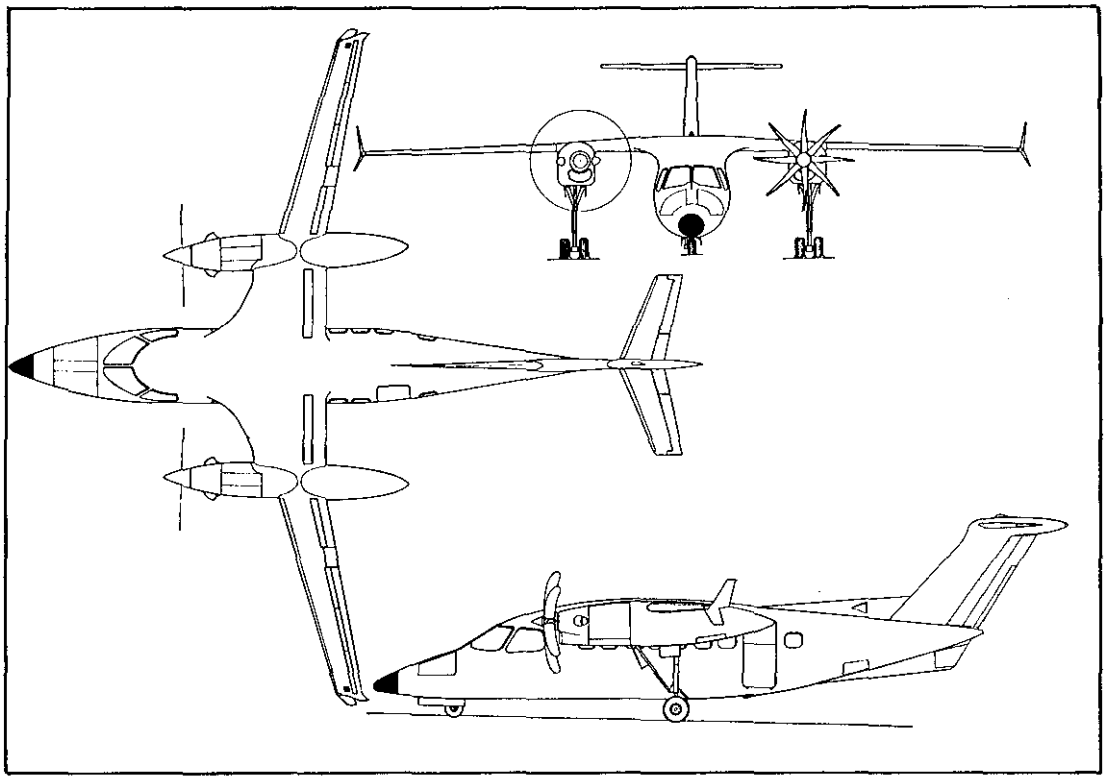

Fig. 1 Three-view of the VATLIT '85 airplane

†Ackers Distinguished Professor of Aerospace Engineering, Associate Fellow AIAA
*Research Engineer, Member AIAA

Following will be a discussion of the particular areas of interest of this design: configuration, aerodynamics, propulsion, stability and control, structures and performance.

Configuration

The final configuration was arrived at after a number of design iterations, aimed at optimizing the various, conflicting, design variables. Two of the variables that have to be considered in an early stage of the preliminary design are wing loading and power loading. It was clear that the cruise speed requirement would be the most important as far as engine power was concerned. A sensitivity study was performed with wing area, lift-to-drag ratio and Mach number as variables. Figure 2-A shows that an increase in wing area results in a drag increase for constant lift. The well-known Breguet range formula[4] shows that range increases with lift-to-drag ratio, all other parameters remaining unchanged. Figure 2-B shows that an increase in wing area, for constant lift coefficient, produces a higher lift-to-drag ratio. From Figure 2-C it follows that at a long range cruise speed of Mach .5, an increase in wing area concides with higher lift-to-drag ratio; hence, an increase in range. However, at a high speed cruise of Mach .7, the opposite is the case. Crossplotting lift-to-drag and drag coefficient as function of speed and wing area produces Figure 2-D.

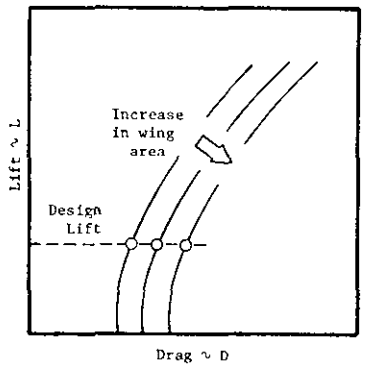

Fig. 2-A Configuration parameter study

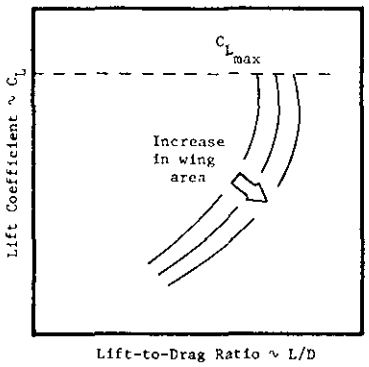

Fig. 2-B Configuration parameter study (continued)

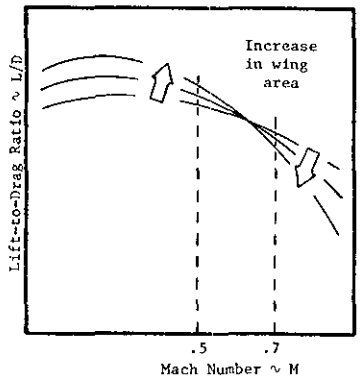

Fig. 2-C Configuration parameter study (continued)

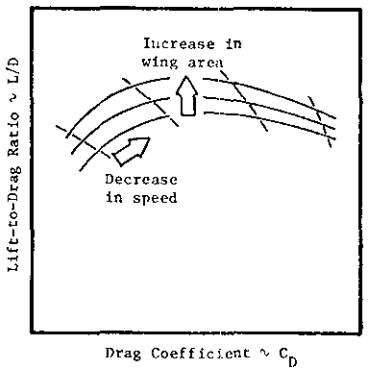

Fig. 2-D Configuration parameter study (continued)

Using these data, an initial estimate of wing area can be made. This estimate was later refined when more precise calculations showed that for a modest increase in power required for cruise, a significant decrease in wing loading could be achieved, as evidenced in Figure 3. This also improved field performance.

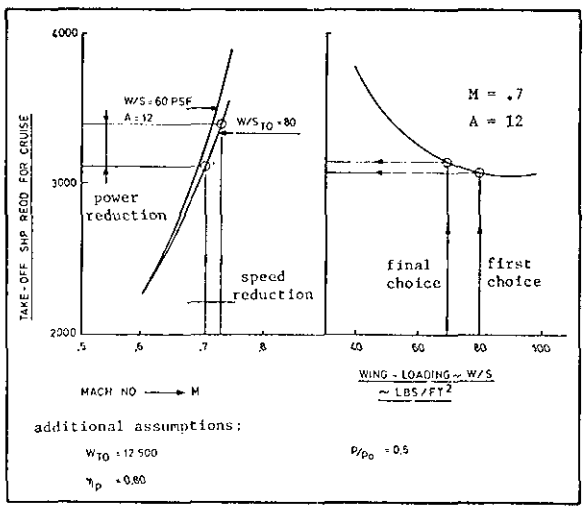

Fig. 3 Sensitivity of cruise speed and wing loading on SHP required

The relatively high wing loading posed problems for field performance (minimum speed) and fuel requirements. The first could be relieved by using full span fowler flaps, which in turn dictated the use of spoilers for roll control. The second problem was attacked in several ways. The possibility of nacelle tanks was considered, but they produce a large shift in center of gravity due to fuel burn-off. Also retraction of the main landing gear would be more difficult. Fuel in the fuselage *a la* Learjet would pose the same center of gravity problem. Fuel in the wing center section seemed the best solution, and a high-wing configuration was chosen. Aerodynamically a high-wing configuration has certain advantages over a low-wing configuration, one of them being the advantageous effect an extended wing-body junction fairing can have on pitching moment. This space can be utilized as fuel tanks.

The use of propfans of relatively small diameter allows more freedom in placement of the engines. Because of landing gear stowage requirements the best solution anticipated was to incorporate wing-mounted engines, with extended nacelles for the main landing gear.

The horizontal tail was positioned at the top of the vertical tail to keep it out of the propwash of the propfans, thereby eliminating pitch trim changes as a result of power setting changes and also to reduce vibration transmitted to the fuselage through the horizontal tail.

To provide stand-up room for the passengers and yet to keep wetted area at a minimum, the fuselage was designed with an elliptical cross-section. Figure 4 shows the fuselage with the standard configuration for 10 passengers. Baggage space is provided for in the rear of the cabin near the entrance door, directly accessible during flight.

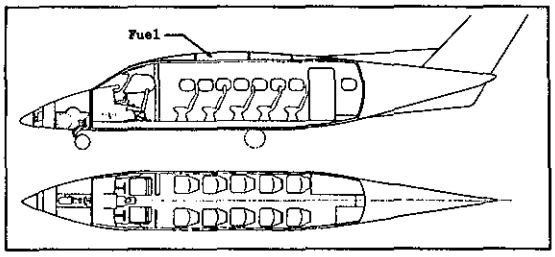

Fig. 4 Cabin layout

Aerodynamics

Recent aerodynamic developments used in this design are the GAW-1 wing section and the Whitcomb winglets.[5] The GAW-1 wing provides high lift-to-drag ratios at the cruise angle of attack (the high wing loading requires a relatively high angle of attack in cruise flight). By tailoring the wing-fuselage and nacelle fairings, this can be optimized; and any adverse shock waves in those areas will be precluded. Also the onset of Mach buffet is delayed to higher Mach numbers, while use of relatively high wing thickness ratios is still possible. Some characteristics of the GAW-1 section are presented in Figure 5; the generous increase in maximum lift coefficient compared to older wing sections is evident.

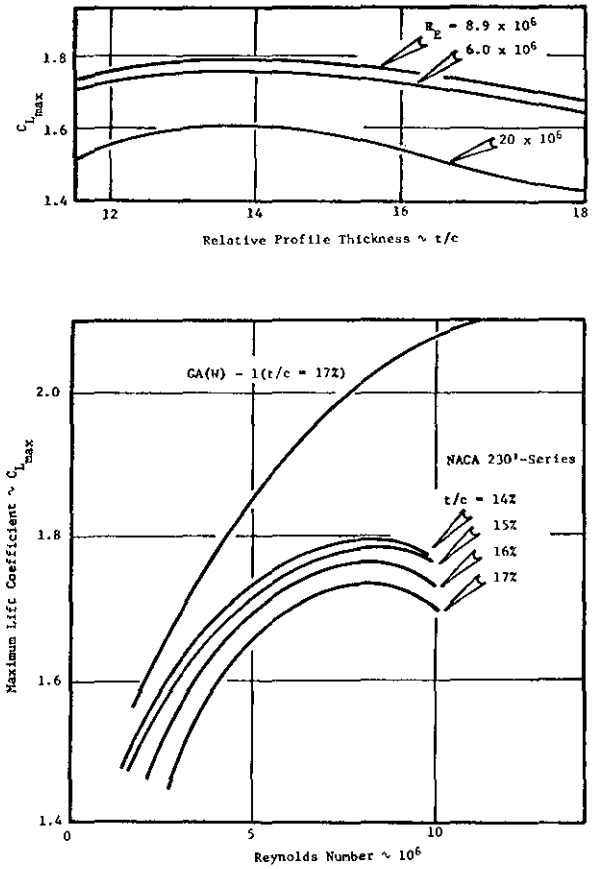

Fig. 5 Prediction of $C_{L_{max}}$ for GA(W)-1 profile with t/c = 17%

The use of high thickness ratio is favorable for internal wing volume available for fuel.

The Whitcomb winglets effectively increase aspect ratio and diffuse the wing-tip vortex, which translates into a reduction in induced drag, particularly noticeable at higher angles of attack.

The GAW-1 wing section combined with full-span fowler flaps provides the high maximum lift coefficients needed for adequate field performance, especially landing. Figure 6 presents the calculated total airplane lift coefficient as a function of angle of attack and flap deflection. No leading-edge slat system was needed to achieve the desired lift coefficients.

Using conventional, established methods[4], the drag polars of the airplane were computed as shown in Figure 7 for various flap deflections, while gear is up.

As mentioned before, the wing-fuselage fairings were shaped such as to favorably affect the fuselage pitching moment in cruise flight, thereby reducing trim drag.

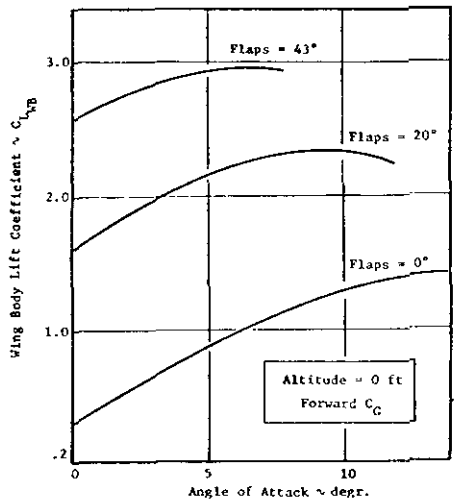

Fig. 6 Lift curve slope for wing-fuselage combination at different flap settings

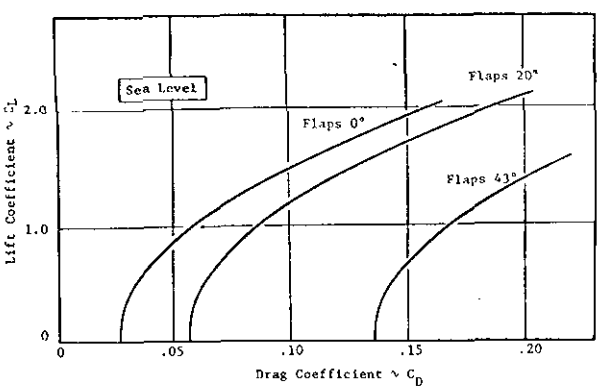

Fig. 7 Drag polars of the VATLIT '85 for various flap deflections and gear up

Propulsion

Propfan

The efficiency of a turboprop decreases rapidly after a cruise Mach number of .6 to .65 has been reached. For higher cruise Mach numbers the turbofan is in common use; but the efficiency is lower than that obtained by the turboprop at low Mach numbers, while the specific fuel consumption is considerably higher. The propfan concept, which is initiated by NASA and Hamilton Standard[6,7], fills the gap between the turboprop and the turbofan (Figure 8).

The propfan is a small-diameter, highly loaded, multi-bladed, variable pitch, unducted propulsor. The eight-bladed propeller incorporates thin supercritical airfoil sections with a 3-4% thickness ratio. The outer blade sections (outside of 2/3 radius) have a sweep angle of 30°. The installed

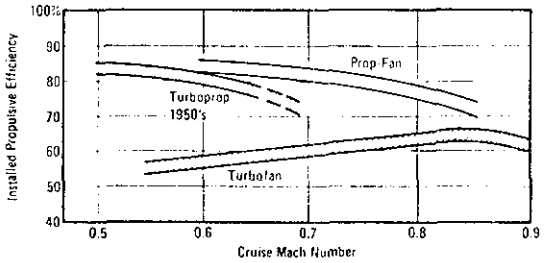

Fig. 8 Installed cruise efficiency for three propulsion systems (Source: Hamilton Standard)

efficiency is calculated according to the SBAC method[8] and the Von Mises momentum method[9], which have been updated and suited to the propfan concept. The SBAC method resulted in an installed efficiency of 82.7%. The Von Mises method produced a slightly higher (installed) efficiency (cruise Mach number = .7).

Engine

Advanced technologies in the near future will allow high thermal efficiencies, high turbine temperatures, favorable power-to-weight and favorable power-to-volume ratios.[10] A suitable engine for the VATLIT '85 was not available. The Project Engine PE 1985 is a prediction of the performance of a turbo engine which could fit in the Propfan concept, based on the thermodynamic relations of the gas turbine.[11,3] The engine is optimized for cruise conditions at 10,700 m and for a Mach number of .7. Figures 9 and 10 give the maximum takeoff, cruise and climb performance of the PE 1985 project engine as function of Mach number and altitude.

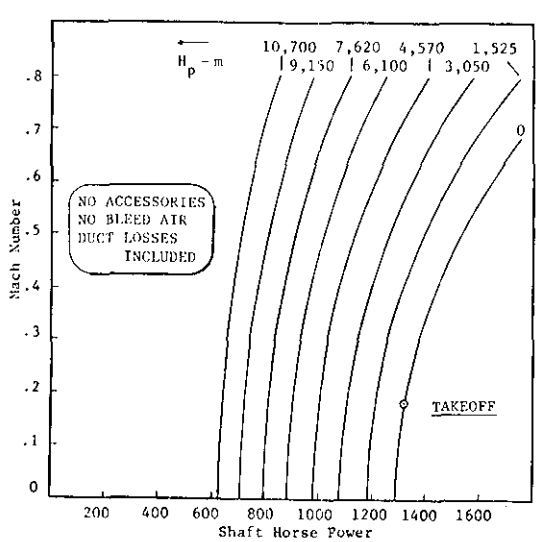

Fig. 9 Maximum continuous performance of the PE 1985 project engine as function of Mach number and altitude

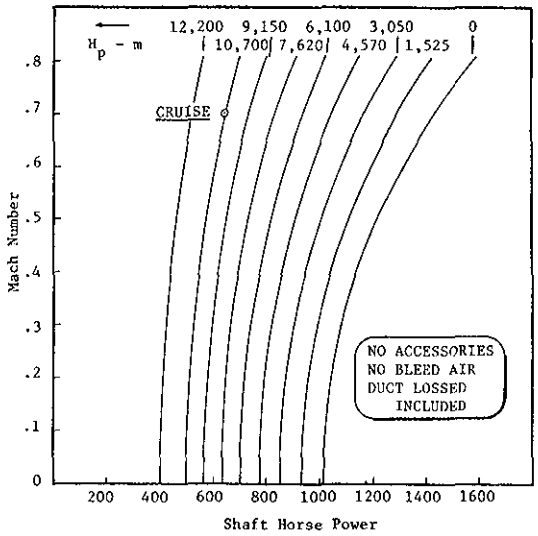

Fig. 10 Maximum cruise and climb performance of the PE 1985 project engine as function of Mach number and altitude

The application of the Propfan concept, including the PE 1985 project engine, has the following impact on the design of the VATLIT airplane:

- The supercritical airfoil combined with a swept propeller blade allows a higher helical tip Mach number (1.05 in cruise) and higher cruise speeds (750 km/hr) without a big rise in fuel consumption.
- A low specific fuel consumption (SFC = .196 kg/hr/SHP) compared to that of a jet engine under the same flight conditions.
- Relatively small blade diameter (2.15 m) gives more possibilities for choosing the engine (ground and fuselage clearance, stability).
- Interior and exterior noise will easily meet future standards and regulations.

A more detailed report on the application of the Propfan concept is given in Reference 3.

Stability and Control

The specification calls for a simple primary control system with cables and pushrods, supplemented with separate surfaces for autopilot and stability augmentation functions. In the case of failure of any of the separate surfaces, the pilot must still have enough authority over the primary controls to fly the airplane manually. It must be possible to make a Category III A instrument landing with standard equipment.

The location of the separate surfaces on the airplane is shown in Figure 11. It can also be seen that they are actuated independently. The advantage is that deflections of these control surfaces do not feed back to the controls in the cockpit, as is the case with most general aviation airplanes today. To mention an example: The yaw damper of many general aviation airplanes is mechanized through the autopilot servos which are tied

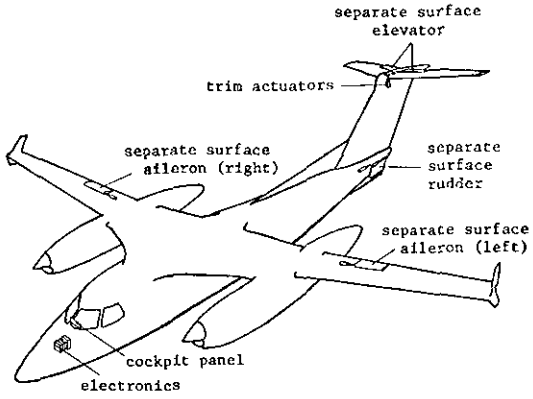

Fig. 11 Location of separate surfaces on the airplane

to the rudder cables. This means that when adjustments are made to the yaw rate, the rudder pedals are moving. In a crosswind landing, this characteristic is highly undesirable to the pilot; and normally the yaw damper will be turned off, although it is probably needed badly.

The size of the separate surfaces is determined by two factors, one for the minimum and one for the maximum size:

1. Each separate surface must have enough capacity to perform well. One criterion is that 99% of all disturbances caused by turbulence must be handled without interference on the part of the pilot. Due to time constraints, however, a different approach has been taken in this project.
2. In the case of a hardover failure, in which a separate surface is stuck at maximum deflection, the pilot must still have enough authority with the primary control surfaces to fly the airplane safely.

The second criterion is another advantage of separate surfaces over conventional systems, where it is much harder to meet servo hardover criteria.

In this project the separate surfaces have been sized as follows:

- The separate surface aileron size was determined with a requirement from Reference 12 that the airplane should be able to attain a bank angle of 45 degrees in 1.9 seconds.
- The ratios of separate surface area to primary control surface area on the rudder and elevator have been taken the same as those for the separate surface stability augmented Beech model 99 used by the University of Kansas.[15]

The locations of separate surface elevator and rudder have been kept close to the vertical tail and fuselage, respectively. This was done to accommodate the necessary actuators in an easy manner. Several spanwise locations were considered for the separate surface aileron. A location right next to the engine nacelles was undesirable because one of the flap tracks was located there, and a location too far outboard had the risk of aileron re-

versal at high speeds. The present location was finally chosen as the optimum one.

After the size and location of the separate surfaces had been determined, a check was made for the hardover failure cases, with satisfactory results.

For the implementation of autopilot and stability augmentation functions, the basic stability characteristics of the airplane were calculated, with the following results:[14]

Table 1 Stability characteristics of the VATLIT airplane

Motion	ω_n(rad/sec)	ζ	$T_{1/2}$(sec)
Takeoff			
Phugoid	.192	.11	32.59
Short period	2.136	.52	.62
Dutch roll	1.772	.151	2.59
Spiral	-	-	-13.20*
Roll	-	-	.48
Cruise			
Phugoid	.092	.048	157.5
Short period	3.528	.353	.56
Dutch roll	3.153	.113	1.94
Spiral	-	-	-8664.4*
Roll	-	-	.45
Approach			
Phugoid	.252	.088	31.01
Short period	1.726	.551	.72
Dutch roll	1.548	.146	3.06
Spiral	-	-	-9.11*
Roll	-	-	.47

where: ω_n = undamped natural frequency [rad/sec]

ζ = damping ratio [-]

$T_{1/2}$ = time to halve the amplitude [sec]

* Note: Negative numbers in the $T_{1/2}$ column denote times to double amplitude rather than halve amplitude.

It can be seen from Table 1 that the spiral is unstable at all times; the remaining motions appear to behave fairly well. The behavior of the spiral cannot be attributed to one particular variable, but rather to a combination of several. Thus it can be seen that some stability augmentation is needed. Several stability augmentation and autopilot modes have been analyzed:

- pitch attitude hold
- pitch damper
- Mach hold
- altitude hold
- glide slope hold
- bank angle hold
- roll damper
- heading hold
- yaw damper

With a selection of suitable gains, most of these modes gave the airplane desirable stability characteristics. An example is shown in Figures 12 and 13, a pitch attitude hold mode with a pitch damper in the inner loop for the cruise condition. Feedback of just the pitch rate tends to improve the short period and deteriorate the phugoid, while feedback of just the pitch attitude angle tends to do the reverse. With a double feedback and proper gain selection, however, both the phugoid and the short period are well damped.

One autopilot mode that needs more analysis is the glideslope hold, but due to time constraints this could not be completed.

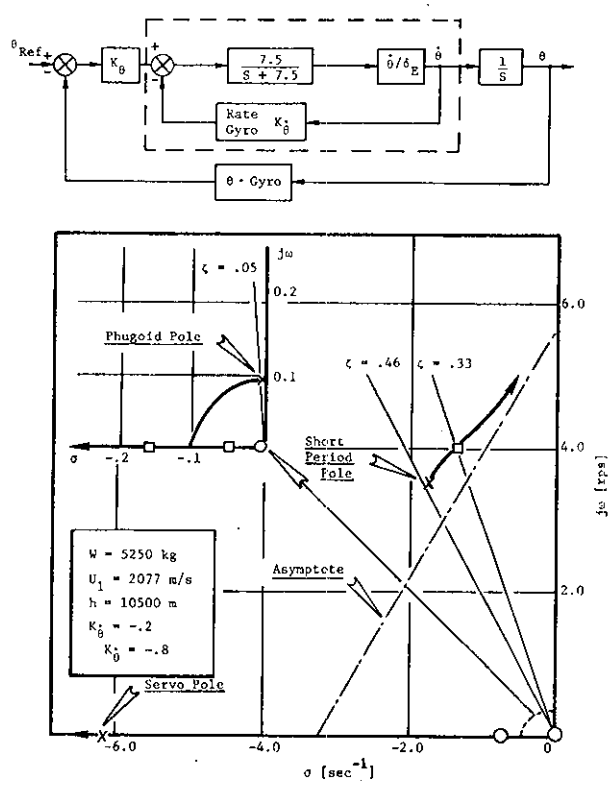

Fig. 12 Root locus for pitch attitude hold in cruise flight

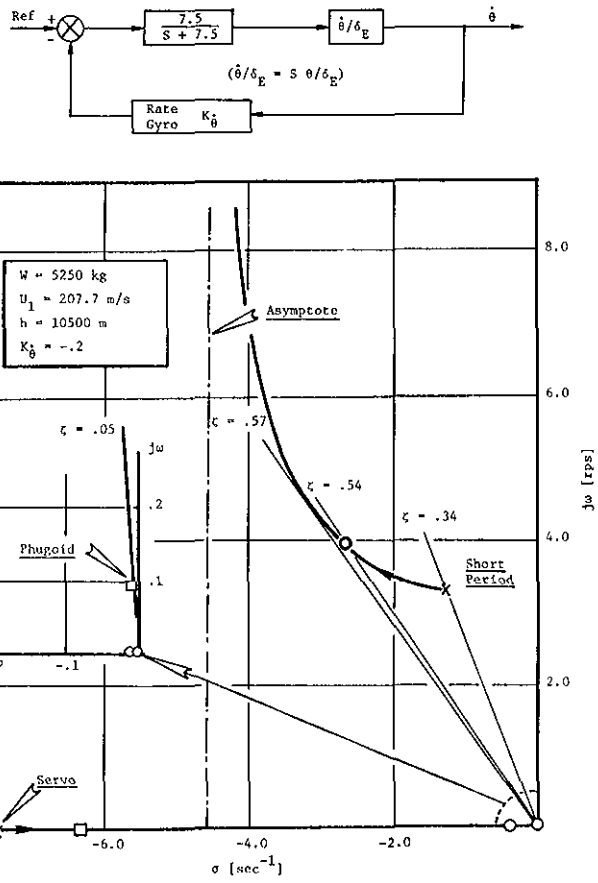

Fig. 13 Effect of pitch damper on root locus in cruise

Structures, Weights and Loads

The primary structure consists of Aluminum 2024 and 7075; the skin is attached to spars, ribs and stringers by bonding. Bonding has many advantages over riveting, such as weight reduction, better fatigue qualities and smoother surfaces. A larger capital investment is needed than for making riveted structures; but it is felt that to build an efficient airplane, this is the way to go. An example is shown in Figure 14. The wing has spars at 10% and at 65% of the local cord, with stringers in between. Since this is the lower skin, several hatches were needed for acces to different parts in the wing. The stringers are all bonded to the skin.

In secondary structures like control surfaces, propeller blades and fairings, use is made of honeycomb, foam techniques and composite materials. However, no calculations have been made on this.

Weights have also been estimated with the assumption that foam and composite structures are used in parts of the airplane. Other than that, methods from Reference 4 have been applied.

An important number for maneuver and gust loads is the maximum zero fuel weight, which has been estimated with the aforementioned methods at 10,700 lbs. The results of calculating these loads are summarized in Table 2. The load factors mentioned in this table apply to limit loads; for ultimate loads, these numbers are 50% higher.

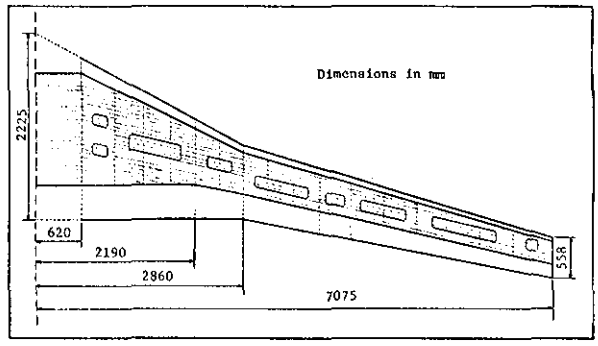

Fig. 14 Wing planform

Table 2 Maneuver and gust level factors

	Maneuvers		Gusts	
Weight	max.	min.	max.	min.
MTOW	2.17	-1	3.25	-1.25
MZFW	3.28	-1	3.68	-1.68

where MTOW = maximum takeoff weight

MZFW = zero fuel weight

Finally, Figure 15 shows the airplane flight envelope for 1-g flights, at maximum takeoff weight. Although the change of the flight envelope with different load factors is not shown, it has been calculated that the maximum maneuver load at an altitude of 35000 ft and M = .7 is about 2.4, which is more than adequate. This number is lower than that in Table 2 because of buffet limitations.

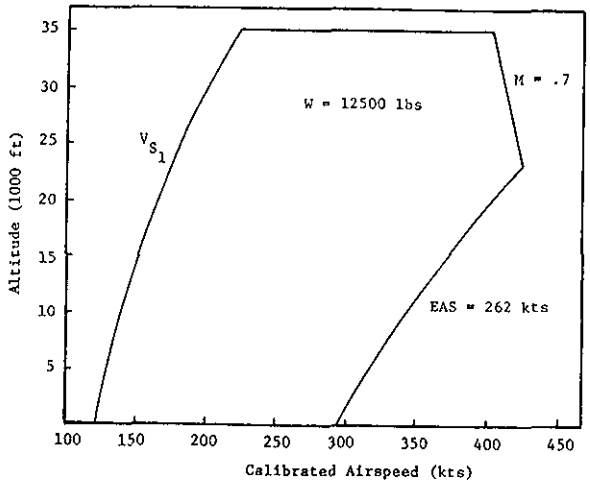

Fig. 15 Airplane flight envelope

Performance

Due to the extreme concept of the design, the performance data are rather interesting. Table 3 shows the most important performance data, with a comparison with two existing airplanes. As already explained earlier, the engines are sized for the cruise condition; thus, the thrust-to-weight ratio in takeoff is fairly high. This coupled with full-span fowler flaps (to offset the small wing area) provides takeoff distances comparable to other aircraft in its class.

Table 3 Performance of the VATLIT '85 airplane compared to the performance of a turboprop and a jet airplane

	VATLIT '85 preliminary design	Beech Super King Air	Learjet 35A
MTOW	5670 kg	5670 kg	7711 kg
OWE	3338 kg	3367 kg	4132 kg
Number of passengers	6-10	6-13	4-8
Fuel quantity	max. 2300 liter	ca. 2100 liter	3524 liter
W/S	341.8 kg/m^2	201.6 kg/m^2	327.6 kg/m^2
W/P	2.18 kg/pk	3.29 kg/pk	247.1 kg/kN(W/T)
A	12	9.8	5.74
Flaps	30% Fowler	single slotted	single slotted
$C_{L_{max}}$(flaps down)	2.8	1.9	
Stalling speed at 0 m, ISA and MTOW	150 km/hr	140 km/hr	171 km/hr
Maximum cruising speed	M=.7;750km/hr	515 km/hr	839 km/hr
at altitude	10700 m	7620 m	13715 m
weight	5670 kg	5670 kg	7711 kg
Economic airspeed (same conditions as above)	M=.5;533km/hr	503 km/hr	774 km/hr
Maximum climb speed at 0 m, ISA and MTOW	23.4 m/s	12.5 m/s	25.9 m/s
Maximum climb speed with one engine at 0 m, ISA and MTOW	8.0 m/s	3.8 m/s	7.5 m/s
Service ceiling with 1 engine	8500 m	5835 m	7710 m
with 2 engines	ca. 14500 m	> 9450 m	12955 m
Takeoff performance over 15 m obstacle at MTOW and ISA	ca. 585 m	786 m	1310 m
Engine Power	2 x 1300 hp	2 x 850 shp	2 x 3500 lbs.
Range at maximum cruising speed	4132 km	3255 km	-
at economic cruising speed	5004 km	3497 km	4466 km
Payload	6 pass.	6 pass.	4 pass.
Fuel economy (distance/block fuel)	3.12 km/kg	2.18 km/kg	1.62 km/kg

A normal takeoff at gross weight, zero wind, standard temperature uses up to 301 m of runway, to a height of 10.7 m; over a 15 m obstacle this would 585 m. It should be noted that with this takeoff distance 80% of the airports in the United States are accessible. A takeoff flap setting of 20° would produce a shorter takeoff distance but would, at the same time, decrease rate of climb.

Calculations showed a balanced field length of 645 m. Again, due to the high thrust-to-weight ratio, the climb performance is outstanding. With two engines at maximum gross weight, a maximum rate of climb of 23.4 m/s is attainable. With one engine inoperative this reduces to 8 m/s, which still compares very favorably with other twin-engine turboprop and jet airplanes (Table 3).

An operational climb to the cruising altitude of 10,668 m at a speed of V_e = 200 kts (M = .45) takes 18.5 min. The service ceiling for the airplane would be 14,500 m. On one engine this would reduce to 8,500 m (Figure A-1).

The cruise technique is always a trade-off between speed and fuel cost. Figure 16 depicts the cruise efficiency of the airplane expressed as specific range (kilometers flown per kilogram fuel). The economical cruise speed at M = .5 is chosen to provide a maximum specific range during the fuel burnoff.

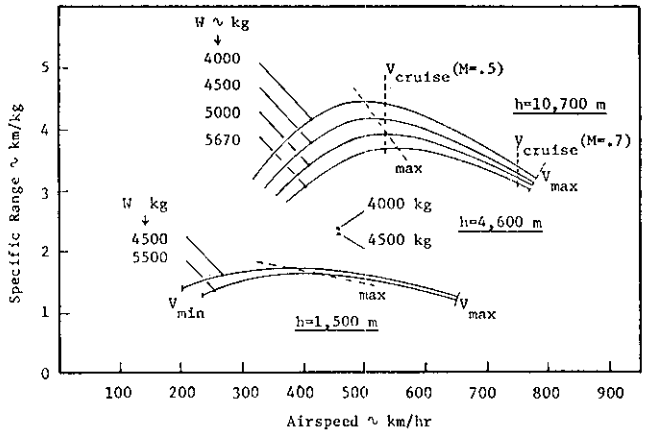

Fig. 16 Specific range as function of airspeed

Figure 17 shows a payload range diagram for both high speed cruise and economic cruise speed.

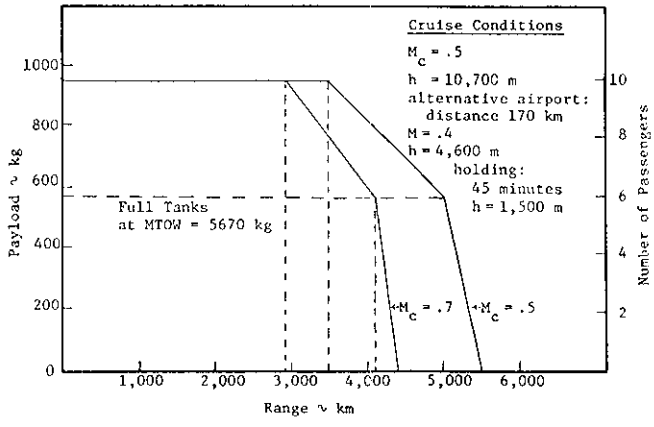

Fig. 17 Payload - Range diagram for high speed cruise and economic speed cruise

For the landing at maximum landing weight of 5670 kg (12,500 lb), 957 m of runway is needed. One peculiarity of the configuration is the attitude of the airplane in the landing approach. Due to the use of full-span fowler flaps, the pitch angle of the airplane at a speed of 1.3 V_S with full flaps is -9.5 degrees. This provides the pilot with a very good view during approach.

Conclusions

A description has been given of a preliminary design study of an advanced light twin business aircraft. The specification called for a turboprop in the Beech Super King Air class with increased performance. As was shown, the application of advanced techniques in the areas of structures, aerodynamics, stability and control and propulsion produced a design that met or exceeded the specifications, while retaining a conventional layout. This design exercise showed that exciting results are possible when innovative design techniques and currently available technology are mated from the beginning of the design process.

Acknowledgements

The authors are indebted to the other project members of the VATLIT '85 Design Group: J. Gunnink, Harm Hogenhuis, Anton Joustra and Henk van Leeuwen. Also acknowledged are Professor Hans Wittenberg, the late Professor van Beek, Fred van Deventer and G. Berenschot of the Delft University of Technology for their valuable contributions to the project.

References

1 J. F. Eijsink, F. M. W. A. Grosveld, J. W. Gunnink, A. J. M. v.d. Hoeven, H. Hogenhuis, A. Joustra, B. van Keppel, H. J. M. van Leeuwen, "Preliminary Design of a Very Advanced Technology Light Twin (VATLIT '85) with Propfans," Memorandum M-288, parts A, B and C, Delft University of Technology, Department of Aerospace Engineering, Delft, Netherlands, August 1977 (in Dutch).

2 J. Roskam, "Designing the 1985 VATLIT," Astronautics & Aeronautics, p. 50-61, October 1976.

3 F. M. W. A. Grosveld, "The Application of the Prop-Fan Concept in Preliminary Design of a Very Advanced Technology Light Twin (VATLIT '85)," AIAA/SAE/ASME paper No. 79-1343, 1979.

4 Torenbeek, E., "Synthesis of Subsonic Airplane Design," Delft University Press, Delft, Netherlands, 1976.

5 R. Whitcomb, "A Design Approach and Selected Windtunnel Results at High Subsonic Speeds for Wingtip Mounted Winglets," NASA TN-D 8260, July 1976.

6 F. B. Metzger and C. Rohrbach, "The Prop-Fan - a New Look in Propulsors," AIAA paper No. 75-1208, 1975.

7 C. Rohrbach, "A Report on the Aerodynamic Design and Windtunnel Tests of a Prop-Fan Model," AIAA paper No. 76-667, 1976.

8 Anonymous, "SBAC-Standard Method of Propeller Performance Estimation," Society of British Aircraft Constructors Ltd., April 1950.

9 Von Mises, "Momentum Theory - Outline of Propeller Theory," McGraw-Hill Book Company, Inc., New York, 1945.

10 B. S. Gatzen and S. M. Hudson, "General Characteristics of Fuel Conservative Prop-Fan Propulsion System," SAE paper No. 751085, 1975.

11 H. Wittenberg, "Prediction of Off-Design Performances of Turbojet and Turbofan Engines Based on Gasdynamic Relationships," Delft University of Technology, Department of Aerospace Engineering, Delft, Netherlands, March 1976.

12 Anonymous, "Military Specification - Flying Qualities of Piloted Airplanes," MIL-F-8785B (ASG), August 1963.

13 Anonymous, "Final Report on the Flight Test Program for a Separate Surface Stability Augmented Beech Model 99," Flight Research Laboratory, KU-FRL 364, University of Kansas, Lawrence, Kansas, July 1976.

14 J. Roskam, "Flight Dynamics of Rigid and Elastic Airplanes," Roskam Aviation and Engineering Corporation, Lawrence, Kansas, 1976.

Appendix A

The most important data of the VATLIT '85 airplane are the following:

Dimensions:

Span:	14.11 m (46.3 ft)
Overall length:	14.92 m (49.0 ft)
Height:	4.33 m (14.2 ft)
Cabin length:	7.20 m (23.6 ft)
Cabin width:	1.50 m (4.92 ft)
Cabin height:	1.60 m (5.25 ft)
Wing area:	16.59 m^2 (178.5 sq ft)
Aspect ratio:	12

Accommodations:

2 pilots and 10 passengers,
baggage in the rear of the cabin.

Weights and Loadings:

Operational weight empty:	3370 kg (7430 lb)
Max. takeoff/landing weight:	5760 kg (12500 lb)
Max. wing loading:	342 kg/m^2 (70.0 lb/sq ft)
Max. power loading:	2.18 kg/hp (4.81 lb/hp)

Engine:

Turboprop Project Engine PE85, based on thermodynamic relations of the gas turbine.
A four-stage compressor is driven by one-stage turbine.
A two-stage free turbine drives the propeller axis by means of a geartrain.
Takeoff power (SL/ISA, static) = 1300 shp.
Eight-bladed, reversible pitch, constant speed propfans of 2.15 m (7 ft) dia., blade activity factor of 150 and an integrated design lift coefficient of 0.125.
Integral fuel tanks in wing and bladder-tanks in center section with total capacity of 2300 liter.

Systems:

Separate Surface Stability Augmentation System.
Hydraulic system, cabin pressurization with bleed air from engines, max. cabin pressure differential 8.5 psi.
Electric system with 2 starter/generators and 2 Nicad batteries, anti-icing with air

from engines.
Full span, 30% chord Fowler flaps, spoilers, ailerons.
Engine performance computer.
Optimum flight path computer.

Performance:

Max. cruise speed at 10700 m (35000 ft):
750 km/h (405 kts).
Long range cruise speed at 10700 m (35000 ft):
533 km/h (288 kts).
Max. rate of climb, 2 engines: 23.4 m/sec (4600 fpm).
Max. rate of climb, 1 engine out:
8.0 m/sec (1575 fpm).
Stalling speed:
150 km/h (81 kts). Flaps down.
Service ceiling, 2 engines:
14500 m (47500 ft).
Service ceiling, 1 engine out:
8500 m (27880 ft).
Takeoff field length (FAR Part 25):
585 m (1920 ft).
Landing field length (FAR Part 121):
957 m (3140 ft).
Range with max. payload (10 pass.) and high speed cruise technique:
4132 km (2230 N Miles).
Range with max. fuel (6 pass.) and long range cruise technique:
5000 km (2700 N Miles).
NBAA fuel reserves including 45 min. holding and 200 N Miles diversion.

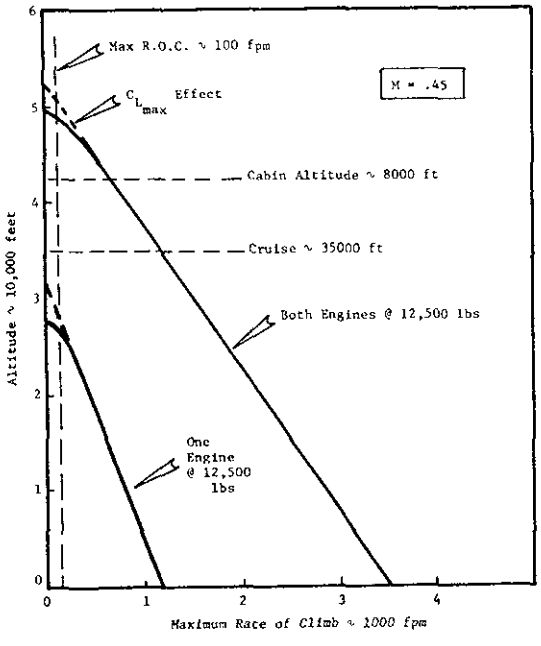

Fig. A-1 Maximum rate of climb as function of altitude for a climb technique with a constant equivalent airspeed of V_E = 200 kts