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ADVANCED COMMUTER AIRCRAFT: HOW TO LEAPFROG THE COMPETITION

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ABSTRACT

The commuter aircraft market is very crowded: too many airplanes for too small a market. Also, the characteristics of these airplanes is such that they do not appeal to the business traveler: noisy, little cabin comfort, poor carry-on capability and they are all different.

It is proposed in this paper to develop a family of commuter airplanes with a very high degree of commonality. It is shown that it is feasible to do so. It is also shown, that the result is a series of commuter airplanes with excellent performance, with good operating economics and with attractive acquisition cost.

I BACKGROUND

Table 1 provides a summary of the characteristics of several existing commuter aircraft. These airplanes are in the 19 to 85 passenger range and all carry FAR 25 (or equivalent) certification.

The following observations are offered:

a) Most are manufactured outside the USA
b) Most are 'old' technology airplanes
c) Most are not built in large numbers
d) Most do not offer jet transport size cabins
e) Most offer poor ride qualities and high interior noise levels
f) Most, when different types are combined in one airline, offer the operator serious problems in cost of training, spare part inventory and maintenance.

II A NEW LOOK

Table 2 lists a number of technologies which, when simultaneously integrated into a new 'Super Regional Airliner'(SRA), will yield an airplane with improved performance and competitive operating costs.

Some major problems with existing commuter airplanes are those listed as c)

Table 1 Typical Commuter Airplanes, 1984

Type	Pax	Seat Pitch (in)	Cabin Length (ft)	Cabin Height (ft)	Cabin Width (ft)	Take-off Power (shp)	Take-off Weight (lbs)	Max. Fuel (lbs)	Max. PL (lbs)	Cruise Speed (kts)	Max Cruise Alt (ft)
USAC Turbo DC3	42	34	41.0	6.6	7.7	2,752	26,900	4,966	10,700	180	20,000
CASA 212-200	26	30	21.3	5.9	6.9	1,800	16,427	3,538	4,922	187	25,000
Shorts 330	30	30	31.1	6.5	6.5	2,396	22,900	3,840	7,500	189	20,000
Shorts 360	36	30	36.2	6.5	6.5	2,654	26,000	3,840	8,800	217	20,000
Embraer EMB120	30	31	45.1	5.8	6.9	3,180	23,809	5,732	7,198	294	29,000
CN235	39	31	31.8	6.2	8.8	3,400	28,658	8,818	7,924	245	28,500
SF340	35	30	34.7	6.0	7.1	3,260	27,000	5,896	6,841	267	25,000
HS748	48	30	46.6	6.3	8.1	4,560	46,500	11,205	11,266	270	25,000
DHC-8	36	31	30.2	6.2	8.2	4,000	33,000	5,612	9,410	269	25,000
F27-500	50	30	52.4	6.8	8.5	4,040	45,000	9,090	11,400	253	20,000
DHC-7	50	32	39.5	6.4	7.0	4,480	44,000	9,925	11,375	228	21,000
F28Mk 4000	85	29	50.3	6.7	10.2	19,800 lbs	73,000	17,240	22,500	447	35,000
BA146 -100	82	33	50.6	6.7	11.1	27,880 lbs	82,250	20,640	19,000	367	30,000

Note: All data in this table are based on Business and Commercial Aviation, April, 1984

Table 2 Technologies for the SRA

1. Composite or Al-Li primary structure for fuselage and lifting surfaces
2. Full flight performance management system
3. Fuel management and CG display
4. Natural laminar flow, on 40 percent chord of all lifting surfaces
5. Natural laminar flow on first 20 percent of fuselage
6. Six-bladed composite propellers
7. Powerplant is controlled like a turbofan installation
8. TKS leading edge deicing on all Lifting surfaces
9. Radial tires, common to all SRA's
10. Acrylic-Polycarbonate-Acrylic flush mounted windshield
11. Electromechanical self-optimizing flight controls
12. Ride control system
13. Cabin noise below that of B737
14. Flight rated APU for power stand-by
15. Handling qualities the same for all SRA's

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through f) before.

To provide the operators with cost improvements and at the same time provide the manufacturer with a solid profit potential, one solution is to develop a family of SRA's with the following features:

1) Common flight deck
2) Common fuselage cross section
3) Common handling characteristics allowing for cross-certification of pilots
4) Common flight control actuators
5) Common landing gear wheels and tires
6) Commonality in structures and in systems to as high a degree as possible

Such a family of SRA's would have the following to offer to the operators:

a) Reduced acquisition cost
b) Reduced direct operating cost
c) Reduced spares inventory cost
d) Reduced maintenance cost
e) Reduced training cost

To the manufacturer such a family of SRA's would offer:

a) Reduced development cost
b) Reduced production tooling cost
c) Increased profit potential plus a long, efficient production program

Designing commonality into families of airplanes is by no means a new idea. What is new here, is that it is proposed to design from scratch a family of airplanes ranging from 24 to 84 passengers with the commonality features listed as 1 through 6 before. To accomplish this will require a significant up-front research and development effort.

The remainder of this paper presents a possible design approach to such a family.

III CONFIGURATION SELECTION

1. Fuselage

The fuselage diameter is selected at 130 in. This provides comfortable four abreast seating with the possibility of going to five abreast. Ample overhead storage is provided. This is considered to be an essential feature, if business travelers are to be dislodged from other modes of transportation.

Figure 1 shows the proposed fuselage cross section. Cabin and fuselage dimensions for four members of the family of SRA's are presented in Table 3.

It is proposed to offer the SRA's to operators in increments of one passenger row.

Figure 2 shows the fuselage layouts for the two extremes: a 24-pax and a 84-pax airplane.

2. General Layout

A three-surface configuration is selected for the following reasons:

1) Allows for minimum trim drag according to Ref.1
2) Easy to stretch over the wide range required here
3) Easy to trim with large Fowler flaps on the wing and the correspondingly high maximum lift coefficients

Three different wing torque boxes are needed to cover the family. To allow for this degree of structures commonality, several variants within each family group will have to have strutted wings.

A high wing layout was selected to allow for strutting the wing at the high gross weight end of the family. This is a desirable feature to keep the weight down, while maintaining some structural commonnality. A high wing also seems to be preferred by many operators.

The powerplants are turbo-props with five-bladed, counter-rotating pusher propellers mounted in nacelles which are attached to the aft fuselage. The nacelles are angled inward to minimize

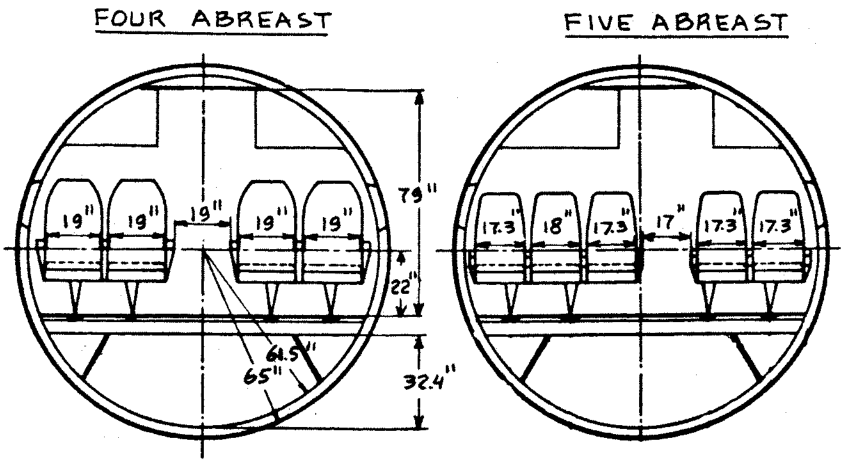

Figure 1 Proposed Fuselage Cross Sections for SRA'S

Table 3 SRA Cabin and Fuselage Dimensions

Pax	Seat Pitch	Seat Rows	Cabin Length (ft)	Fuselage Nose (ft)	Fuselage Tailcone (ft)	Fuselage Length (ft)	Fuselage Fineness Ratio
24	37	6	19.3	16.9	26.5	62.7	5.8
44	37	11	35.3	16.9	26.5	78.7	7.3
64	37	16	51.3	16.9	26.5	94.7	8.7
84	37	21	67.4	16.9	26.5	110.8	10.2

Note: Common fuselage diameter is 10.83 ft

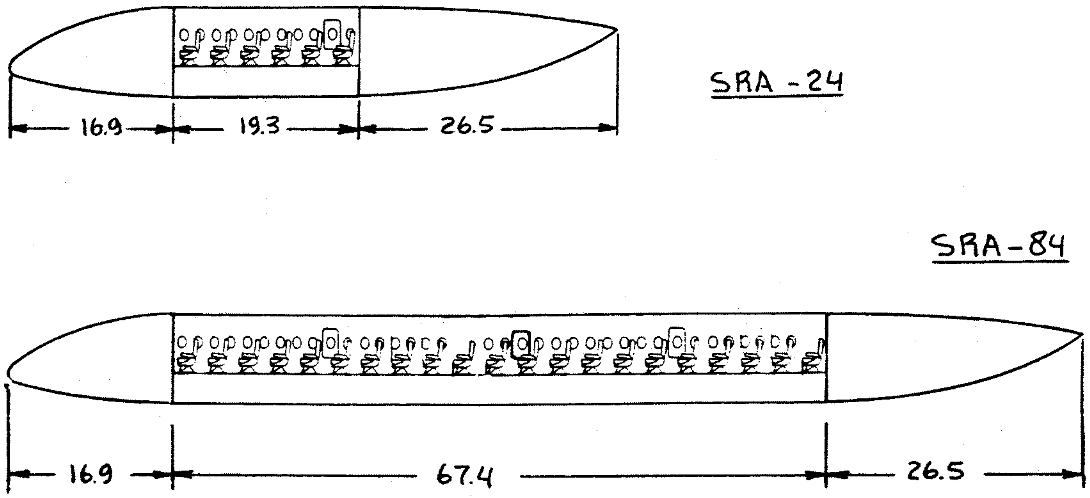

Figure 2 Fuselage Layouts for the SRA-24 and SRA-84

engine out yawing moments.

Figures 3 and 4 show the configurations for the 24 and for the 84 passenger airplanes, calles SRA-24 and SRA-84.

3. Sizing the SRA-24 and -84

Sizing objectives are selected as follows:

Cruise speed: M = 0.6 at 30,000 ft
Range: 700 nm for the SRA-24
1,000 nm for the SRA-84
Fieldlength : 4,000 ft, FAR 25.

Table 4 shows the initial sizing results obtained for the airplanes. The assumed values for $(L/D)_{cr}$ and for c_j are also given. The method used in the sizing process is the fuel-fraction method of Ref.2.

Consistency between the estimated empty weight and gross weight was maintained by using the following equation from Ref.3:

$$W_E = \text{inv.}\log_{10}\{(\log_{10} W_{TO} - 0.3774)/0.9647\}$$

The constants in this equation were determined with a regression analysis on data from 21 regional turboprop transports.

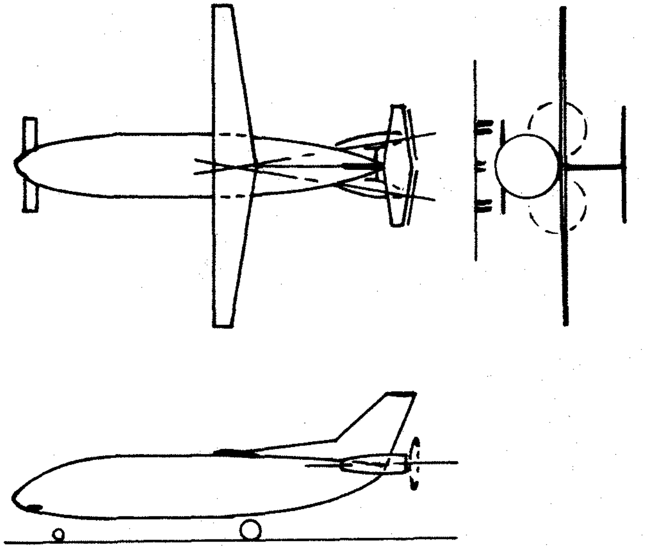

Figure 3 General Arrangement for the SRA-24

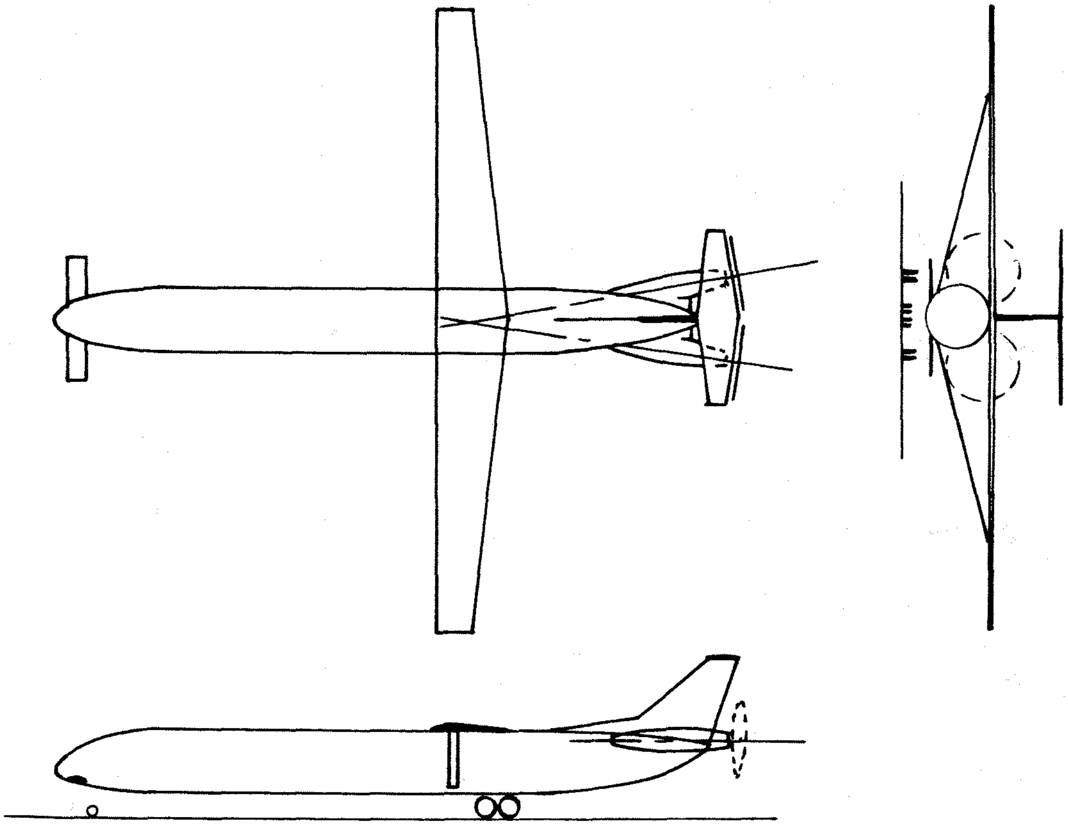

Figure 4 General Arrangement for the SRA-84

Table 4 Results of Preliminary Sizing

Type SRA	Cruise Speed (kts)	Cruise Alt. (ft)	Take-off Weight (lbs)	Payload Weight (lbs)	Crew Weight (lbs)	Fuel Weight (lbs)	Empty Weight (lbs)	Design Range (nm)	Lift-to-Drag Ratio (Assumed)
-24	354	30,000	21,000	4,920	615	3,423	12,042	700	12
-84	354	30,000	81,000	17,220	1,025	13,200	49,555	1,000	17

Notes: 1) Ref.2 gives $c_j = 0.45$ for the specific fuel consumption.
2) 25 percent fuel reserves are included in the sizing results.

Having determined the initial weights, the FAR 25 sizing methods of Ref.2 were used to determine the wing loading, thrust-to-weight ratio and the maximum lift coefficients needed to meet field length and engine-out climb requirements. Figure 5 shows the results of this sizing.

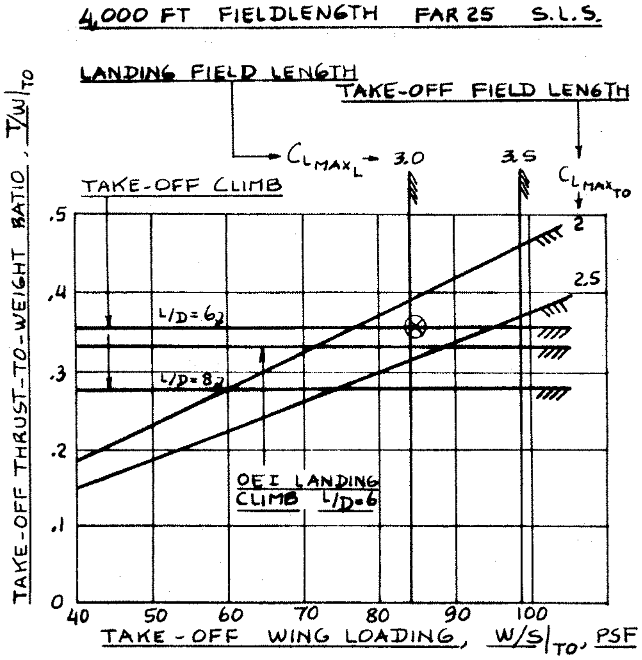

Figure 5 Preliminary Sizing of Wing and Thrust Loading

From Figure 5, the following parameters were selected:

Take-off wing loading, $(W/S)_{TO} = 85$ psf

Take-off thrust-to-weight ratio, $(T/W)_{TO} = 0.35$

Aspect ratio, A = 12

Maximum landing lift coefficient, $C_{L_{max_L}} = 3.1$

Maximum take-off lift coefficient, $C_{L_{max_{TO}}} = 2.3$

With this information it is now possible to size the wing. Since the fuselages for the -24 and the -84 were already determined in Figure 2, the total wetted areas can now be estimated. From the wetted areas, using Figure 6 it is possible to find the equivalent parasite area, f. Note, that the -24 and the -84 are placed at a level of aerodynamic smoothness on par with the jets in Figure 6. With the assumed laminar flow runs, this is quite reasonable.

Table 5 lists the sizing results and also shows the predicted drag data. Note that the estimated L/D values in cruise are higher than those assumed in the weight sizing before. That means, that the sizing process probably overestimated the weigts. No further iterations were performed to take advantage of this.

Note from Table 5, that the -24 is poor in terms of wetted area compared to the -84 and compared to the other commuters listed. The reason is the very large fuselage which penalizes the smaller members of the SRA family.

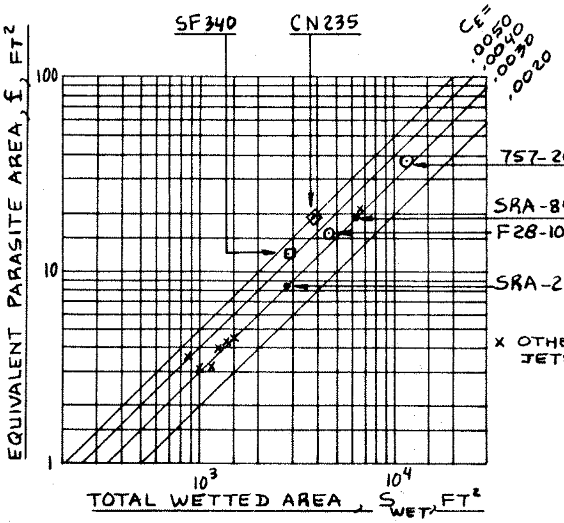

Figure 6 Preliminary Determination of Parasite Area

Table 5 SRA Sizing Results and Comparison with Existing Regionals

Type	Pax	W_{TO} (lbs)	S (ft^2)	S_{wet} (ft^2)	f (ft^2)	C_{D_o}	A	e	$(L/D)_{max}$	$(L/D)_{cr}$
ATR42*	42	34,720	587	3,731	18.3	0.0312	11.1	0.8	14.0	?
SF340*	35	26,000	450	2,793	12.8	0.0285	11.0	0.8	15.5	13.9
CN235*	39	28,660	646	3,805	18.5	0.0286	10.5	0.8	15.2	?
F28-1000*	55	62,000	822	4,566	15.6	0.0190	7.3	0.8	15.6	14.0
SRA-24	24	21,000	247	2,572	8.3	0.0336	12.0	0.85	15.4	13.2
SRA-84	84	81,000	953	6,134	19.0	0.0199	12.0	0.85	20.1	19.4

* The numbers for these airplanes were obtained by analyzing threeviews and other data published in Jane's All The World Aircraft.

4. Selection of Wing Geometry

As shown in Table 5 the wing areas for the SRA family vary from 247 ft^2 all the way to 953 ft^2. Aspect ratio was selected to be 12 and the taper ratio is set at 0.5. Because of the low Mach number, no sweep is required. Figure 7 shows how the wings are laid out for the -24, through -40 models. The other wings are derived from these as suggested in Table 6. There are three families of wings with torque boxes common within each family. To carry the larger bending loads associated with the larger wings needed within each family, wing struts are proposed. With modern computational fluid dynamics it is possible to develop the required strut geometry and strut-to-wing fairings to minimize interference drag. It is suspected, that by proper strut design, it will be possible to eliminate some wing area since the struts can be made to contribute to lift. It is assumed, that laminar airfoils will be used on the struts.

For the wings, the airfoils selected are the KU40A series. These airfoils have been developed with NASA MS(1)-0317 as a starting point. Figure 8 shows the predicted drag characteristics of these airfoils. They are suitable to be used with cruise flaps, to keep $C_{D_{min}}$ aligned with $C_{L_{cr}}$. The cruise flaps are integrated into the Fowler flaps.

5. Flight Control System

The primary flight control system is projected to be a so-called self-optimizing flight control system. That means that a digital computer decides how to move the available flight control surfaces to always optimize:

1) Trimmed L/D
2) Trimmed $C_{L_{max}}$
3) Trimmed $C_L^{3/2}/C_D$
4) Ride characteristics
5) Handling characteristics

To achieve this, it is projected that a primary flight control system will have to be developed which controls the following surfaces:

1) four canardvator segments, two on each side
2) four elevator segments, two on each side
3) twelve wing cruise flaps, six on each side

Each control surface segment will be sized so that only one type of actuator is needed. This will help to reduce cost and allow the actuators to be designed without redundancy.

A primary flight trim system controls the incidence of the canard and that of the horizontal tail. This will allow the trim drag to be minimized at arbitrary cg locations. (Ref.1)

The pilots interface with the control system through side-arm controllers and a fly-by-wire system.

The high lift system consists of Fowler flaps on the wing and on the canard. In any high lift mode, the system is kept automatically in trim.

A possible way to mechanize the flight control system is to use samarium-cobalt actuators. A flight rated APU provides the required stand-by power. In case of failure of the three primary power sources, a standby battery system for one hour of operation is provided.

5. Selection of Empennage

No attempts were made to do detailed stability and control analyses to size the

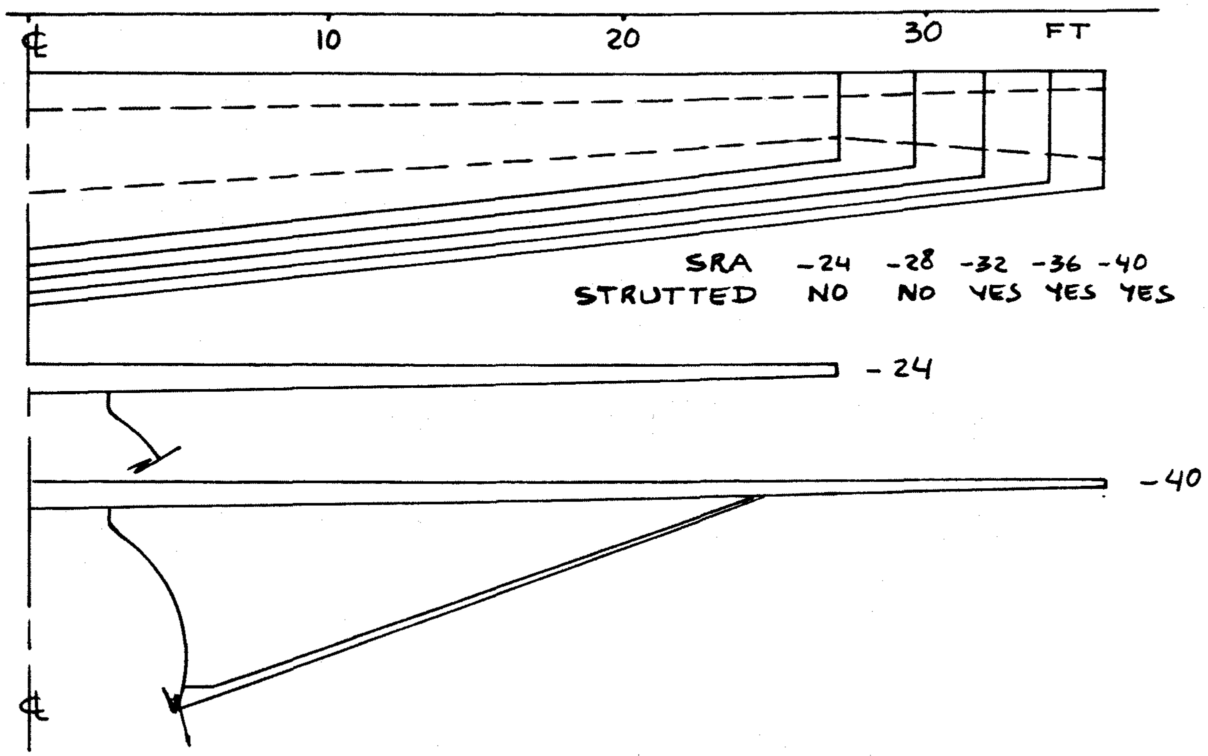

Figure 7 Preliminary Wing Layout for the SRA'S

Table 6 Wing Geometries for SRA Family

SRA Type	Take-off Weight (lbs)	Wing Area (ft^2)	Wing Span (ft)	Root Chord (ft)	Tip Chord (ft)	Torque-box Common to point at: (ft)	Strutted	Strut Attachment at: (ft)
-24	21,000	247	54.4	6.1	3.0	54.4	no	----
-28	25,000	294	59.4	6.6	3.3	54.4	no	----
-32	29,000	341	64.0	7.1	3.6	54.4	yes	24.2
-36	33,000	388	68.2	7.6	3.8	54.4	yes	24.2
-40	37,000	435	72.2	8.0	4.0	54.4	yes	24.2
-44	41,000	482	76.1	8.5	4.3	76.1	no	----
-48	45,000	529	79.7	8.9	4.4	76.1	no	----
-52	49,000	576	83.1	9.2	4.6	76.1	yes	31.4
-56	53,000	624	86.5	9.6	4.8	76.1	yes	31.4
-60	57,000	665	89.3	9.9	5.0	76.1	yes	31.4
-64	61,000	718	92.8	10.3	5.2	76.1	yes	31.4
-68	65,000	765	95.8	10.6	5.3	95.8	no	----
-72	69,000	812	98.7	11.0	5.5	95.8	no	----
-76	73,000	859	101.5	11.3	5.6	95.8	yes	38.4
-80	77,000	906	104.3	11.6	5.8	95.8	yes	38.4
-84	81,000	953	106.9	11.9	5.9	95.8	yes	38.4

Note: all strut attachments are at .76 percent semi-span in relation to the common torque-box.

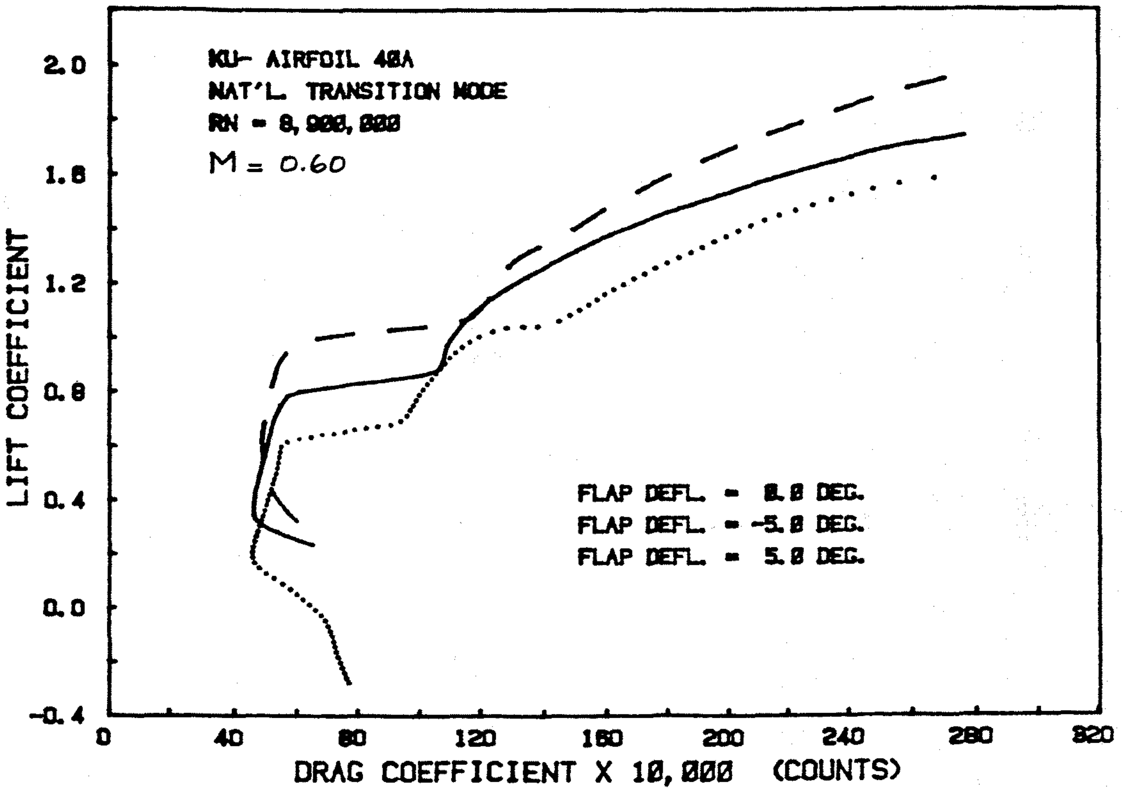

Figure 8 Predicted Drag Characteristics of SRA Laminar Airfoil

horizontal tail and the canard. Based on previous work by the author an area ratio of $S_{emp}/S_{wing} = 0.48$ was selected to account for empennage drag.

The surface layout shown in Figures 3 and 4 are for the moment, arbitrary.

Commonality approaches to the structural design of the empennage for the familie of SRA's needs to be investigated.

IV PREDICTION OF ACQUISITION COST

Two types of cost were predicted:

1) Research and Development
2) Production

The method of Ref.4 was used to make these predictions. A comparison with predicted results for the SF340 is included.

To predict cost, a number of groundrules had to be established. For the SF340 it was assumed, that 4 development airplanes are used and that 500 airplanes are sold over a 120 month period with a production rate of 4.2 per month.

For the SRA's it was assumed, that the family concept would result in a total market of 2,000 airplanes. Over a 120 month production period, this means an average production rate of 16.7 per month. Eight development airplanes were assumed to be needed.

Table 7 lists the predicted costs in 1984 dollars. To arrive at these figures, using Nicolai's method of Ref.4, it was assumed that the following cost bases are valid:

- *Inflation multiplication factor from 1970 to 1984 is 2.5.
- *Engineering hourly costs are: USD 35/hr.
- *Tooling hourly costs are: USD 25/hr
- *Manufacturing hourly costs are: USD 18/hr.

These numbers are most probably optimistic. However, the comparison with the SF340 should still be valid if the assumed production runs are reasonable.

One more point: to predict the costs for the SRA family, it was assumed, that the Nicolai method could be applied to the SRA-60 (sixty percentile member of the family) as if all 2,000 have those costs. Because of commonality in tooling, materials and equipment, it is expected that this assumption is conservative.

A significant cost advantage of the SRA's which was not accounted for, is the fact that the common flight decks and cockpits will represent significant savings in development costs and in flight-manual preparation.

Table 7 Comparison of Predicted Costs of SRA-60 with SF340 (1984 USD)

	SF340 Prediction		SRA-60 Prediction	
Cost Item	Development	Production	Development	Production
Engineering	15,715,000	38,045,000	46,480,000	127,715,000
Development Support	5,016,000		19,163,000	
Flight Test DTE	1,996,000		16,478,000	
Tooling	27,075,000	64,050,000	75,029,000	200,618,000
Manufacturing Labor	24,196,000	305,027,000	70,815,000	1,281,013,000
Quality Control	3,145,000	39,654,000	9,206,000	166,532,000
Manufacturing Materials	3,854,000	177,602,000	13,259,000	1,054,550,000
Totals	80,997,000	624,378,000	250,430,000	2,830,428,000
Development cost written off over:	200 airplanes		800 airplanes	
Production cost written off over:	500 airplanes		2,000 airplanes	
Cost per airplane:	404,985	1,249,000	313,000	1,415,000
Sub-total cost per airplane: first 200		1,653,985 for first 200		1,728,000 for first 800
Engine/Prop cost per airplane		652,000		1,430,000
Avionics cost per airplane		500,000		750,000
Total cost per airplane		2,806,185		3,908,000
Total cost per seat		80,177		65,133

When the cost per seat is computed for the SF340 and for the SRA-60, the result is USD 80,177 and USD 65,133 respectively. This seems to indicate that a venture such as proposed here may indeed become profitable for the manufacturer as well as for the operator, if the fuel used per seat is competitive. That is the subject of the next section.

V PREDICTION OF FUEL USED PER SEAT

To compare the operating economies, only a comparison of trip fuel and fuel per seat is presented. Table 8 gives the results. It is seen that the SF340 has a slight advantage over the SRA-24. However, the SRA-36 is already significantly better. As expected, the relative economies improve as the SRA size goes up. This comparison does not account for the significant operational advantages of the SRA's due to the commonality factors listed before.

VI SUMMARY

It has been shown that the potential exists for development of a family of Super Regional Airliners with a high degree of commonality. Initial cost comparisons indicate that such a family should become profitable to both the manufacturer and to the operators. To initiate the development of such a family of airplanes will require a major investment and the staying power needed to await the program breakeven point.

Table 8 Comparison of Fuel Flows

All data in this table assume a 300 nm mission with a cruise altitude of 25,000 ft

	SF-340	SRA-24	SRA-36	SRA-60	SRA-84
Take-off weight (lbs)	26,000	21,000	33,000	56,500	84,000
Ave. cruise weight (lbs)	24,400	19,700	31,000	53,000	76,600
Wing area (ft^2)	450	247	388	665	953
Cruise speed (kts)	270	300	300	300	300
Cruise C_L	0.49	0.58	0.59	0.58	0.59
$(L/D)_{max}$	15.5	15.4	16.3	18.2	20.1
$(L/D)_{cr}$	13.9	13.2	14.4	16.9	19.4
Required thrust (lbs)	1,755	1,492	2,153	3,136	3,948
Fuel specifics (lbs/lbs/hr)	0.5	0.45	0.45	0.45	0.45
Cruise time (hrs)	1.11	1.0	1.0	1.0	1.0
Fuel used (lbs)	974	672	969	1,411	1,777
Number of passengers	35	24	36	60	84
Fuel used per seat (lbs/seat)	27.8	28.0	26.9	23.5	21.2

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