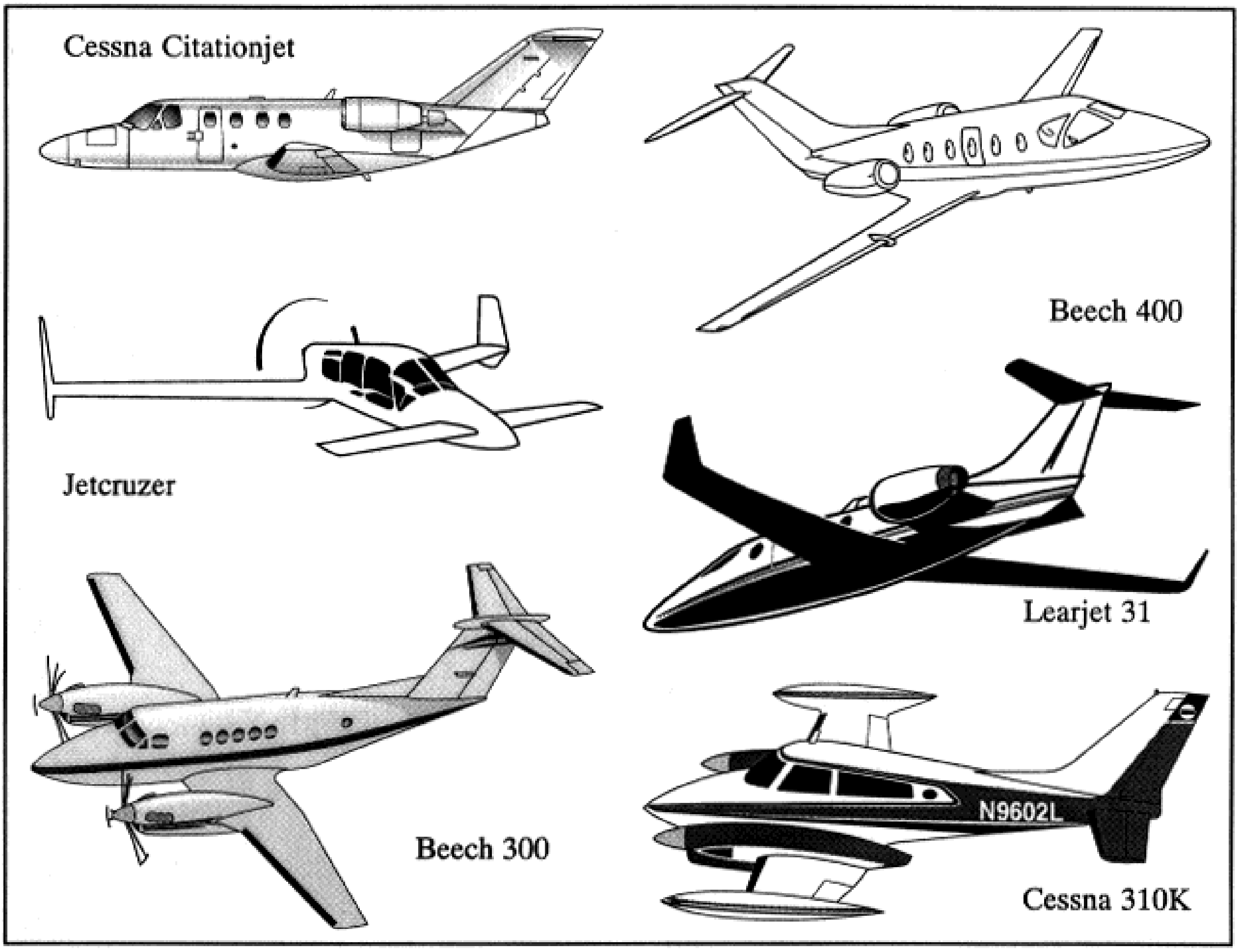
SMALL AIRCRAFT TRANSPORTATION SYSTEM (SATS) PLANNING CONFERENCE



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by: Dr. Jan Roskam
Ackers Distinguished Professor of Aerospace Engineering
The University of Kansas
Lawrence, Kansas

TOPICS TO BE ADDRESSED: PAGE

1) MULTIDISCIPLINARY DESIGN OPTIMIZATION TOOLS

NASA Question:

Can we make intelligent manufacturability and affordability decisions using modern design tools that accurately account for innovations in configuration aerodynamics? Are there issues that are related to testing tools (wind tunnels) for design validation?

Roskam's Response:

I do not believe that there is a significant role for multidisciplinary design optimization tools in the design and development of SATS configurations. One can perhaps "optimize" a Cessna Citation type airplane. A major issue even here is the turn–around time in the aerodynamic/structural analysis of a complete and arbitrary configuration. For configuration CFD to be really useful in advanced design requires a turn–around time of about 5 minutes. In addition it should not take a PhD degree to use such a code. I am told that this capability (using complete Navier–Stokes equations integrated for 1,000,000,000 grid–points) is at least 2–3 computer generations in the future.

Then there is the problem of a rather alarming lack of early structural design/analysis tools. This is the reason why NASTRAN and Flutter analyses cannot come into play until nearly all of the early design decisions have already been made.

All of this this still ignores the problem of educating that rare breed of experienced configuration designers in the use of such tools.

Intelligent manufacturing decisions can be made by using virtual reality tools such as used by Lockheed in designing for manufacturability of the JSF. A problem for small companies here is the acquisition of qualified personnel as well as the capital investments which will be required. For small airplanes I still believe that nothing can beat "horse–sense and experience". A combination of automated aluminum bonding and spot–welding should be considered.

My recent experience with a new business jet design shows that early windtunnel testing as a tool in developing even a conventional configuration is absolutely essential. In that program several aerodynamic design problems were identified during a windtunnel test conducted late in the program (and with a proof–of–concept airplane already flying!). The tests indicated the need for subtle changes in the exterior lines of the airplane which in turn will significantly delay its certification.

In terms of affordability decisions it is essential that the product be designed to have real value to the customer. Any design optimization study should bear this in mind. For a simplified analysis of a value–added–parameter see my response to Topic 8.

2) AFFORDABLE SPEED (SUBSONIC)

NASA Question:

Jim Griswold has an interesting perspective on a "300 mph" rule: slower speed will not meet the goal (DDS around 4x highway speed) and faster speed is wasteful in terms of cost. Is this reasonable?

Roskam's Response:

To provide meaningful personal transportation it will be necessary to consider total trip time and therefore door–to–destination speed or DDS. Its relationship to airplane design cruise speed is developed next.

The door–to–destination–speed (DDS) is defined as follows:

$$DDS = \frac{R_{block} + \Delta R_{ground}}{t_{DDD}} \qquad (1)$$

The block distance, R_{block}, is defined as the airport to airport distance to be flown. The incremental ground distance, ΔR_{ground}, is defined as the added ground distance from doorstep to airport of origin plus that from airport of destination to final destination. The quantity, t_{DDD}, is the time elapsed between doorstep and destination and may be determined from:

$$t_{DDD} = \frac{R_{block}}{V_{block}} + \Delta t_{ground} = t_{flt} + \Delta t_{ground} \qquad (2)$$

The block–speed, V_{block}, may be estimated from:

$$V_{block} = \left(0.7125 + 0.11625\, t_{flt} - 0.00875\, t_{flt}^2\right) V_{cruise} \qquad (3)$$

where it is assumed that: 0.25 hours is spent in climbing at $0.8\ V_{cruise}$
0.15 hours is spent in descending at $0.8\ V_{cruise}$
0.10 hours is spent in ground maneuvering (this is an acceptable assumption only when operating from general aviation airports)

The flight time, t_{flt}, may be estimated from:

$$t_{flt} = \frac{R_{block}}{V_{block}} \qquad (4)$$

The ground travel time, Δt_{ground}, may be estimated from:

$$\Delta t_{ground} = \frac{\Delta R_{ground}}{V_{ground}} \qquad (5)$$

where: V_{ground} is the average speed of ground or highway transportation

ΔR_{ground} is the sum of doorstep–to–airport–of–origin and airport–of–destination–to–doorstep distances

For many general aviation block distance scenarios it is acceptable to approximate Eqn (3) by:

$$V_{block} = 0.85\, V_{cruise} \tag{6}$$

In that case it is possible to show that:

$$DDS = 0.85\, V_{cruise} \frac{\left(1 + \frac{\Delta R_{ground}}{R_{block}}\right)}{\left\{1 + 0.85\left(\frac{V_{cruise}}{V_{ground}}\right)\left(\frac{\Delta R_{ground}}{R_{block}}\right)\right\}} \tag{7}$$

Figure 1 shows the relationship between the DDS and the cruise speed for a range of values of $\Delta R_{ground}/R_{block}$. It is clear that to meet the NASA objectives of 4 times highway speeds, cruise speeds must be between 250 and 350 kts depending on the ground distance which must be covered when flying a certain block distance. This shows that Griswold's conjecture about the minimally acceptable cruise speed is correct.

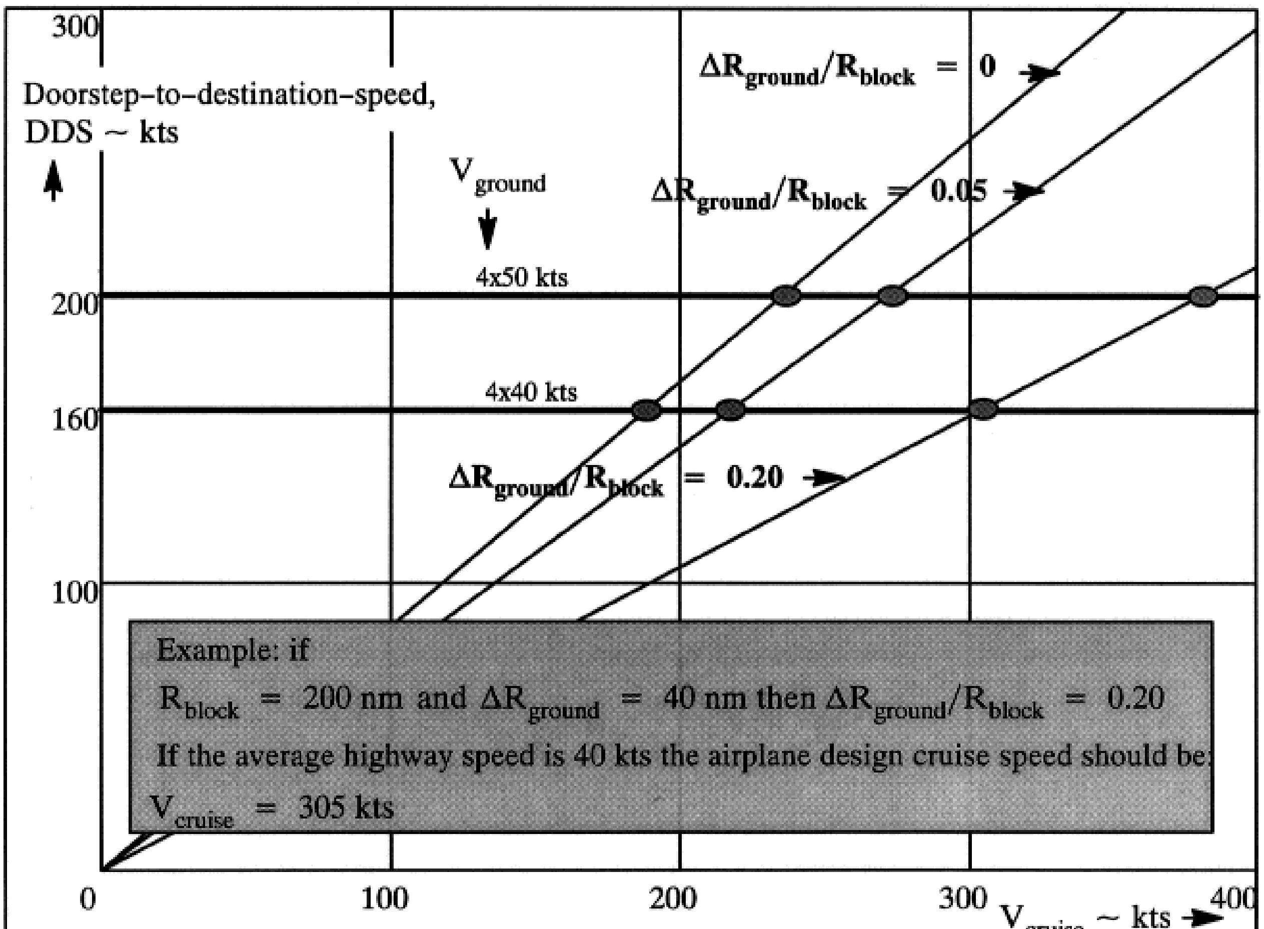


Figure 1 Effect of Ground Distance and Cruise Speed on Door–to–door–speed

To show that significantly greater cruise speeds are wasteful from a cost viewpoint consider the following rationale.

A 10% increase in cruise speed requires approximately a 21% higher cruise thrust keeping all other design variables constant. This will result in a 21% greater fuel burn in cruise with commensurate increase in fuel cost.

Assuming the same thrust–to–weight ratio at takeoff, a 21% increase in cruise thrust translates into a similar increase in take–off weight. Using RAND costing estimates of Ref.1 it can be shown that the manufacturing cost of the airplane would increase by 12%.

These cost increases have to be weighed against the benefit of time savings. If the trip–time is 3 hours, 1 hour of which is spent on the ground, the time savings of a 10% increase in cruise speed will be 12 minutes. This magnitude of time saving requires a very highly paid individual to justify. Therefore, again, I believe that the Griswold conjecture is correct.

3) AFFORDABLE SPEED (SUPERSONIC)

NASA Question:

Is now the time to consider corporate supersonic travel? A 4–6 passenger supersonic aircraft would likely be able to fly supersonic over land.

Roskam's Response:

Since the Concorde became operational, various efforts have been made to get a supersonic business jet (SSBJ) program moving. They all stalled and I believe that cost is the main reason. In the following design analysis the author shows that if a "Bill Lear" approach is taken, a supersonic business jet may very well be viable.

An illustration of the cost problem with SSBJ's is given in Figure 2.

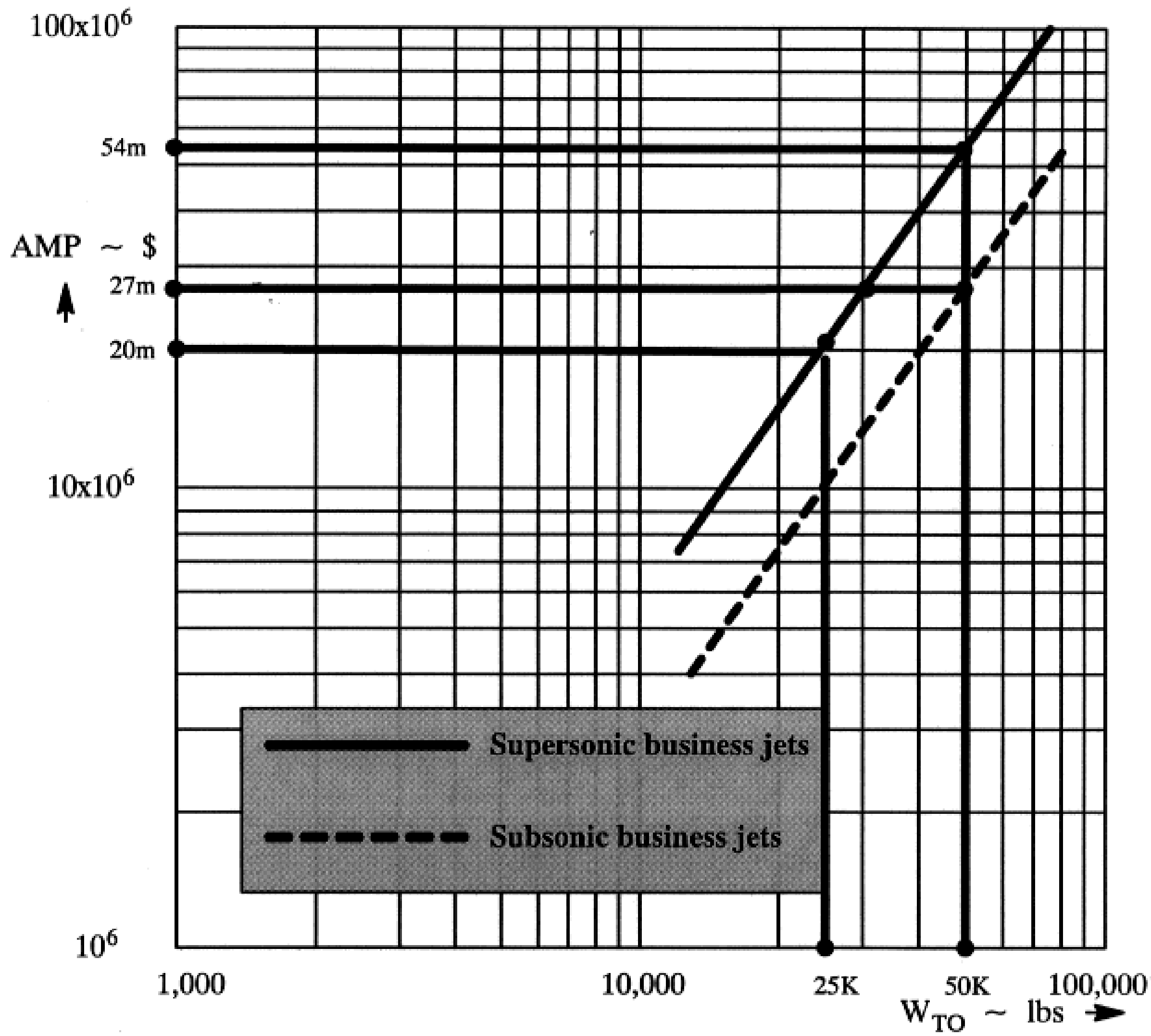


Figure 2 Price Trends for Subsonic and Supersonic Business Jets for 2000

For subsonic business jets the AMP (Airplane Market Price) is given by the lower line. Supersonic business jets, for comparable weights would carry a substantially higher price tag as suggested by the upper line. A typical subsonic, trans–atlantic business jet has a take–off weight of around 50,000 lbs. The corresponding airplane market price (AMP) is around $ 27 million. A supersonic airplane of the same weight would cost about $ 54 million, or twice as much.

The RDTE cost for three prototypes would be somewhere between 1 and 1.5 billion dollars!

If, while keeping transatlantic range, the weight could be brought down to around 25,000 lbs, the price could come down to around $ 20 million. At that price, the SSBJ might well become a commercially viable product.

By applying Bill Lear's approach to designing a small, but still comfortable subsonic business jet (which became the Learjet Model 23), to a supersonic business jet, this price and weight target can be achieved. To keep the airplane small, it is specified as a 4–passenger, 2–crew airplane with a cabin somewhat larger than that of the Cessna 525 Citationjet: 6 ft diameter, 21 ft long. Of course, the fineness ratio of the SSBJ would be much larger to reduce wave drag and to reduce sonic boom effects. Table 1 provides the design mission specification for this airplane.

When doing a preliminary design study of any new, advanced airplane, a number of assumptions must be made regarding aerodynamic and engine technology. The following assumptions were made for this small, supersonic business jet airplane:

1) The cruise lift–to–drag ratio at M=2 and 60,000 ft is 7.5. This is a little better than the Concorde, but in 1998 probably realistic for this airplane.

2) The specific fuel consumption of the engines in the augmented mode is 1.15 at M=2 and at 60,000 ft. This is probably very optimistic but may be realizable.

3) The structural design of this airplane and the simplicity of its cabin amenities allow for a ratio of empty weight to take–off weight which is less than 0.5. This can only be achieved with very careful structural design and analysis, wasting no material anywhere. It is very optimistic and the author can see the structures people brace themselves for an argument.

The suggested use of augmented turbofans must be explained. An alternative to using augmented turbofans would be to use turbofans sized for sufficient thrust at M=2 and 60,000 ft without augmentation. The military refer to this as super–cruise and the F–22 fighter is an example of this.

The problem with super–cruise for a commercial airplane is that the thrust–to–weight ratio at take–off becomes very large. The following example calculation will illustrate this. If the supersonic lift–to–drag ratio is 7.5 and the begin cruise weight of the airplane is 23,000 lbs, the required thrust at 60,000 ft and M=2 is 23,000/7.5=3,067 lbs. For a super–cruising engine, the corresponding thrust under static, sea–level conditions is obtained by dividing this number by the atmospheric density ratio at 60,000 ft. The result is a take–off thrust of 3,067/0.0949=32,315 lbs. Note that this would give the airplane a take–off thrust–to–weight ratio larger than 1.0!!! That would be o.k. (and in fact desirable) for a fighter but not for a commercial airplane. It is noted that various Gulfstream–Sukhoi designs (Ref.1) also used augmented turbofans.

Table 1 Mission Specification for a 4 Passenger Supersonic Business Jet

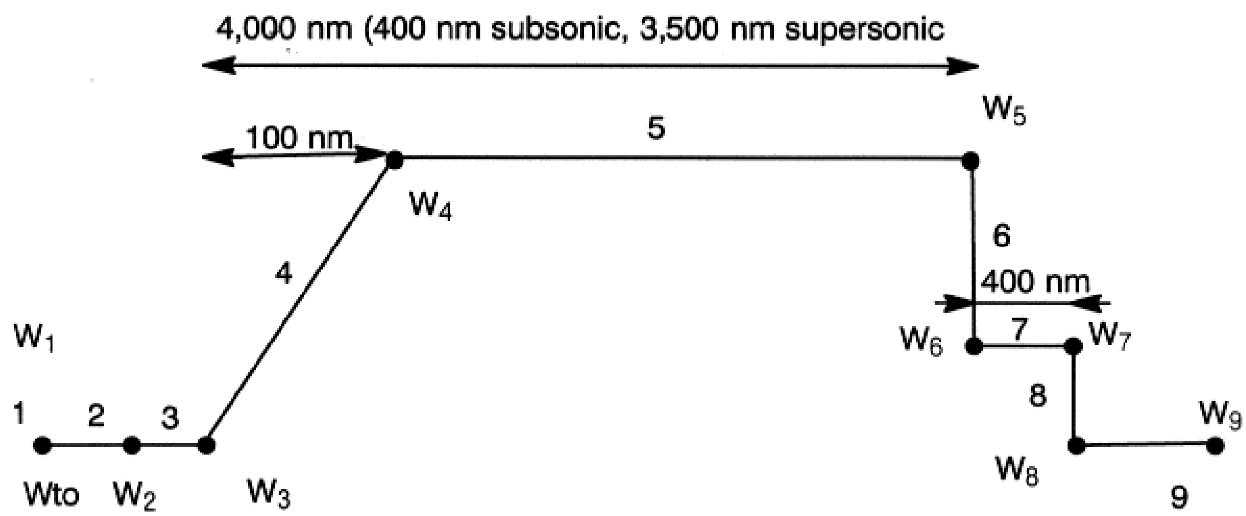
Role: To carry four executives over 4000 n.m. at Mach 2, in a comfortable, specially designed business environment at moderate cost.

Payload: 4 Passengers, @200 lbs each plus 50 lbs of baggage
Crew: Cockpit, 2, @200 lbs each plus 50 lbs of baggage
Total crew + payload weight = 1,500 lbs

Performance:	Range:	Still air range of 4,000 nm plus 400 nm to a suitable alternate destination. Range credit for climb: 100 nm.
	Speed:	Mach 2 at 60,000 ft (1,147.2 KTAS)
	Fieldlength:	5,000 ft at sea-level, 95 deg. F. day
	Climb:	Direct climb to 60,000 ft in 20 minutes is desired
	Maneuvering:	Capable of 1.05g turn at 60,000 ft and M=2
Powerplants:	Three, augmented turbo-fans	

Pressurization: 8,000 ft cabin at 60,000 ft **Certification:** FAR 25

Mission Profile:



1) Engine start and warm-up
2) Taxi
3) Takeoff
4) Climb to 60,000 ft (take range credit) in 20 minutes
5) Cruise
6) Descend
7) Cruise to alternate
8) Descend
9) Landing, taxi, shutdown

By using the AAA (Advanced Aircraft Analysis) software of Ref.2 it is possible to calculate the take–off weight, the empty weight and the mission fuel weight required to carry out the mission specified in Table 1. The results are given in Table 2.

Table 2 Predicted Mission Weights for a 4–Passenger Supersonic Business Jet

$W_{TO} = 25,757$ lbs $W_E = 11,600$ lbs $W_F = 12,528$ lbs

$W_{PL} = 1,500$ lbs $W_{tfo} = 129$ lbs

Mission Profile	Weight in lbs	Fuel used in lbs
Start and warmup	25,757	129
Taxi	25,628	128
Take–off	25,500	255
Climb, 100 nm range credit	25,245	730
Cruise 400 nm subsonic	24,515	1,313
Cruise 3,500 nm supersonic	23,202	8,652
Cruise 400 nm subsonic to alternate	14,550	984
Descend	13,566	204
Land/ Taxi/ Shutdown	13,363	134

Note that the takeoff weight is predicted to be 27,757 lbs. At this weight the price of the airplane should be around 20 million dollars. Table 2 also shows the fuel used as the mission progresses.

Some readers will recognize the fact that the take–off weight is predicted to be more than double the empty weight. Achieving this would constitute quite a design feat! Many aircraft designers would seriously doubt that this is possible. This comment goes along with assumption 2) made before.

To assess the level of difficulty in designing even this small SSBJ, it is of interest to consider the sensitivity of the estimated take–off weight to changes in aerodynamic, engine and structural design technology. This would serve to illustrate the level of difficulty designers are confronted with in realizing this airplane. Table 3 shows these sensitivities as determined with the AAA software. The meaning of these sensitivities is as follows:

1) The sensitivity of take–off weight with changes in engine specific fuel consumption (s.f.c.) in the supersonic cruise mode, $\partial W_{TO}/\partial c_j = 94,000$ lbs/unit c_j , means that if the engine s.f.c. turns out to be 1.25 instead of the assumed 1.15, the take–off weight required to fly the same mission would increase by 9,400 lbs. Such a change would invalidate the airplane! There would have to be a clear understanding between the airframer and the engine manufacturer about installed engine s.f.c.'s.

Table 3 Predicted Mission Weight Sensitivities for a 4-Passenger Supersonic Business Jet	
$\partial W_{TO}/\partial c_j = 94,000$ lbs/unit c_j	$\partial W_{TO}/\partial W_E = 2.2$
$\partial W_{TO}/\partial L/D = -14,400$ lbs/unit L/D	$\partial W_{TO}/\partial R = 31$ lbs/n.m.

2) The sensitivity of the estimated take-off weight to changes in the empty weight, say as a result of structural inefficiencies, $\partial W_{TO}/\partial W_E = 2.2$, means that if the empty weight turns out to be 1,000 lbs more than assumed, the take-off weight required to fly the same mission would increase by 2,200 lbs. Such a change would be difficult to absorb in this airplane!

3) The sensitivity of the estimated take-off weight to changes in the supersonic lift-to-drag ratio, (due to optimism by the aerodynamics department), $\partial W_{TO}/\partial L/D = -14,400$ lbs/unit L/D , means that if the supersonic lift-to-drag ratio turns out to be 6.5 instead of the assumed value of 7.5, the take-off weight required to fly the same mission would increase by 14,400 lbs. Such a change would completely invalidate the airplane! Predicting supersonic drag accurately is clearly essential.

4) The sensitivity of the estimated take-off weight to changes in the supersonic cruise range, say as a result of customer needs, $\partial W_{TO}/\partial R = 31$ lbs/n.m. , means that if the customer wants a supersonic range of 4000 n.m., instead of 3,500 n.m., the take-off weight required to fly the same mission would increase by 500x31=15,500 lbs. Such a change would completely invalidate the airplane. These sensitivities dramatically illustrate the difficulties encountered in the design of a supersonic business jet.

Figure 3 shows a sideview of the proposed fuselage. Figure 3 also shows a comparison with the fuselage of the Cessna Citationjet. Note the much larger fuselage length of the SSBJ. Figure 4 shows the proposed geometry of the wing in comparison with the wing of the Citationjet. Note that the wing areas are fairly close. The SSBJ will have to carry a large amount of fuel in the fuselage.

Admittedly, this proposed SSBJ is a small airplane. It is based on the same philosophy used by Bill Lear in the original Model 23. That airplane was widely predicted to be a non-starter. Instead, it lead to a whole new industry. The author believes the same can happen with the proposed, small SSBJ.

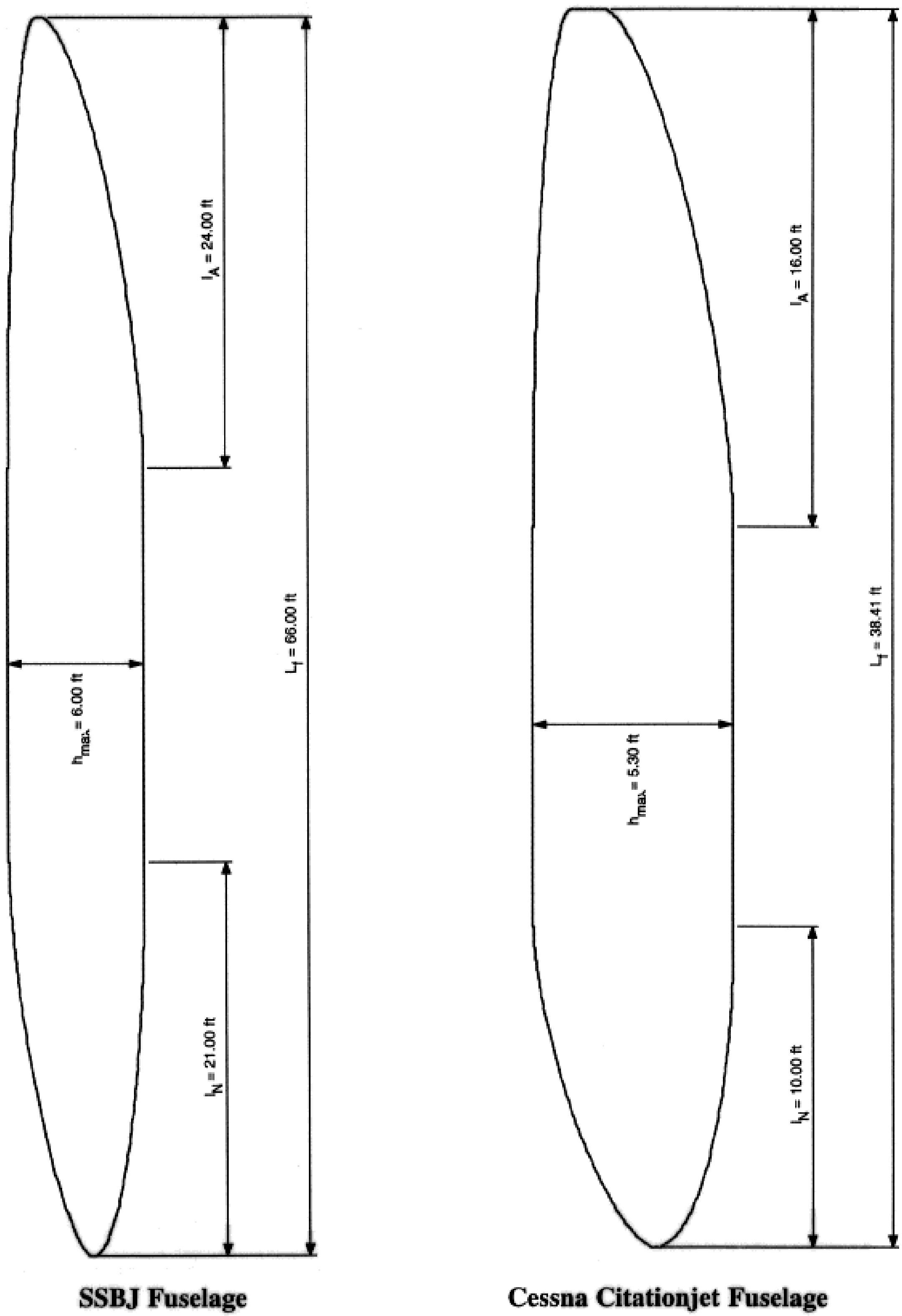


Figure 3 Comparison of the Fuselages of the Proposed SSBJ and that of the Citationjet

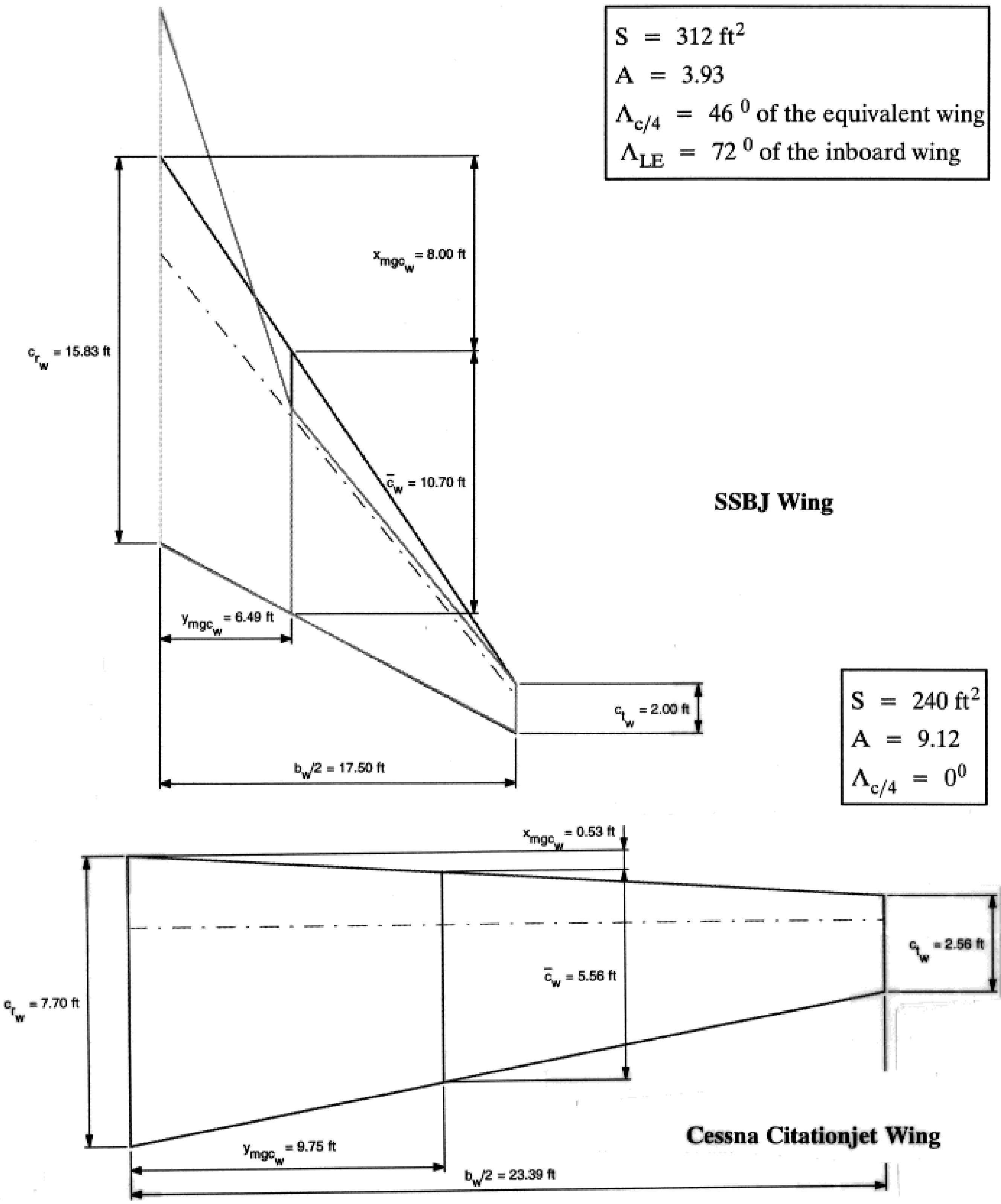


Figure 4 Comparison of the Wing Planform of the Proposed SSBJ and that of the Citationjet

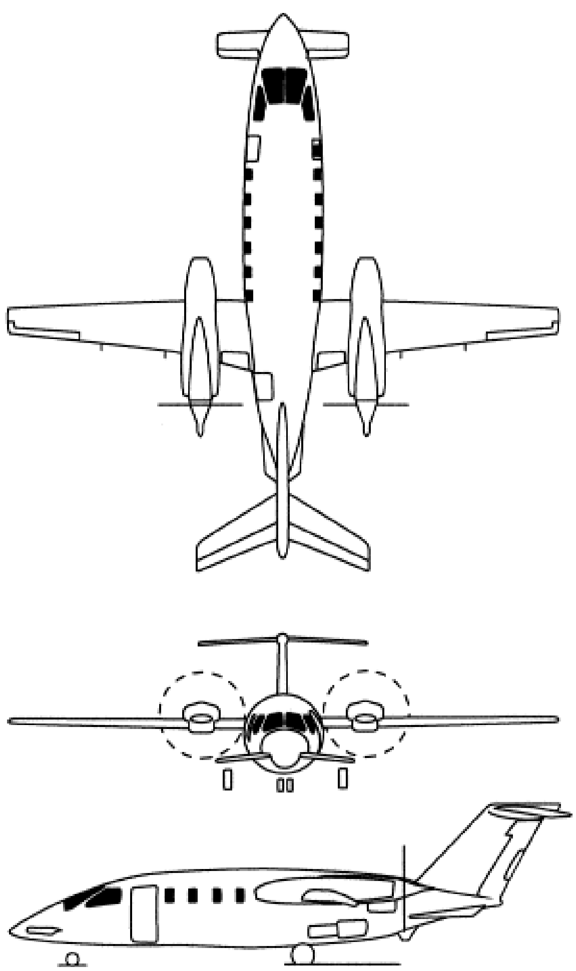
4) LAMINAR FLOW

NASA Question:

Is now the time to move to active laminar flow control for SATS aircraft? Small amounts of suction in the pressure recovery region on wings of zero or even moderate sweep can maintain full chord laminar flow. What about extensive fuselage laminarization?

Roskam's Response:

Assuming that the entire boundary layer of a small jet airplane can be laminarized and that 20% of the cruise drag is induced drag, the required cruise thrust could be reduced roughly by 40%. That would be a very attractive drag reduction target provided the required systems cost and complexity can be made acceptable. A more realistic assumption is to laminarize the flow over the wing alone. Since the ratio of wing wetted area to total wetted area is about 3:1 the resulting reduction in required cruise thrust is only about 13%. That still is rather significant and the systems design, cost and complexity consequences should be investigated. The author views this as a fairly long term objective and would not commit the farm to it for a short term project.



5) LOW-SPEED CONSIDERATIONS

NASA Question:

A key to making "four times the speed of highways" accessible for more people is to provide aircraft with high cruise speeds, yet with low approach and landing speeds. For decades the ratio of cruise to stall speed for light aircraft has been stuck at about 3:1. The last significant advancement in speed ratio occurred for the Piper Malibu. Is now the time to consider alternatives to traditional high lift systems for light aircraft? Can landing speeds of 50 kts (or slower) on a 300 kts (or faster) aircraft be practically (affordably) achieved?

Roskam's Response: My response is in three parts.

5.1) Discussion of small airplane design design practice

For most small airplanes a typical ratio of cruise speed to landing stall speed is 3:1.

The Beech/Raytheon Bonanza has a trimmed maximum lift coefficient of about 2.0 and a cruise speed to landing stall speed ratio of 3.5.

For the SOCATA TBM–700 this ratio is 4.9. The latter is achieved with a take–off wing loading of 34 psf and 67% span single slotted Fowler flaps with a trimmed maximum lift coefficient of 2.6.

The NASA funded KU Redhawk project of the early 70's pioneered this type of flap and wing–loading combination on a modified Cessna Cardinal airframe.

It is interesting to note that airplanes like the Piper Malibu and the SOCATA TBM–700 are the only types which have applied this simple design philosophy.

5.2) Discussion of jet transport design practice

In transport jets ratios of cruise speed to landing stall speed of 5 are fairly typical. In these cases wing loadings are typically in the range of 100–140 psf and maximum trimmed lift coefficients are as high as 3.2. The latter are achievable with trailing edge, slotted Fowler flaps and appropriately designed leading edge devices. The Airbus A320 has a trimmed maximum lift coefficient of 3.2.

5.3) Discussion of future small airplane design practice

In future light airplanes there is no reason at all why maximum trimmed lift coefficients of at least 2.6 with mechanical flaps should not be considered.

A recent design study of a four–engine STOL transport by my students has shown that by using all the fan–air of two of these four engines and blowing it at the flaps can result in a trimmed maximum lift coefficient of 5.5–6.0. This would result in take–off and landing distances of around 200–300 ft.

6) RIDE QUALITIES

NASA Question:

As the early inhibitors to GA revitalization are diminished (affordability, ease–of–use and safety), will comfort become the next big issue? What alternatives should be on our list for ride quality advancements?

Roskam's Response:

Yes, ride qualities will be an issue and should be taken into account. The following simple analysis shows clearly what might be done.

The gust sensitivity of an airplane can be thought of as the product of load–factor–to–angle–of–attack sensitivity, n_α, and the gust induced angle of attack at a given speed–altitude combination. The parameter, n_α, can be written as follows:

$$n_\alpha = \frac{C_{L_\alpha}\bar{q}}{W/S} \tag{8}$$

where: C_{L_α} is the airplane lift–curve slope in 1/rad

W/S is the wing loading in psf

$\bar{q}$ is the dynamic pressure in psf

The gust induced angle of attack, α_{gust}, can be written as:

$$\alpha_{gust} = U_{gust}/U \tag{9}$$

Figure 5 shows how gust sensitivity, n_α, varies with wing loading for typical transport jets and for typical, small, general aviation airplanes.

Things are even worse when the effect of altitude on gust magnitude is considered. At 10,000 ft the design gust is 50 fps. For the GA airplane this yields a gust induced angle of attack of 0.15 rad.

At 35,000 ft the design gust is 37.5 fps. For the jet transport this yields a gust induced angle of attack of 0.05 rad. The jet transport therefore enjoys a factor of about 9 in lower sensitivity to turbulence.

The lesson is clear. To achieve the same ride comfort as that of the transport jets the design wing loadings and the design cruise altitudes have to be increased. These design trends are synergistic with the high lift observations made under item 5.

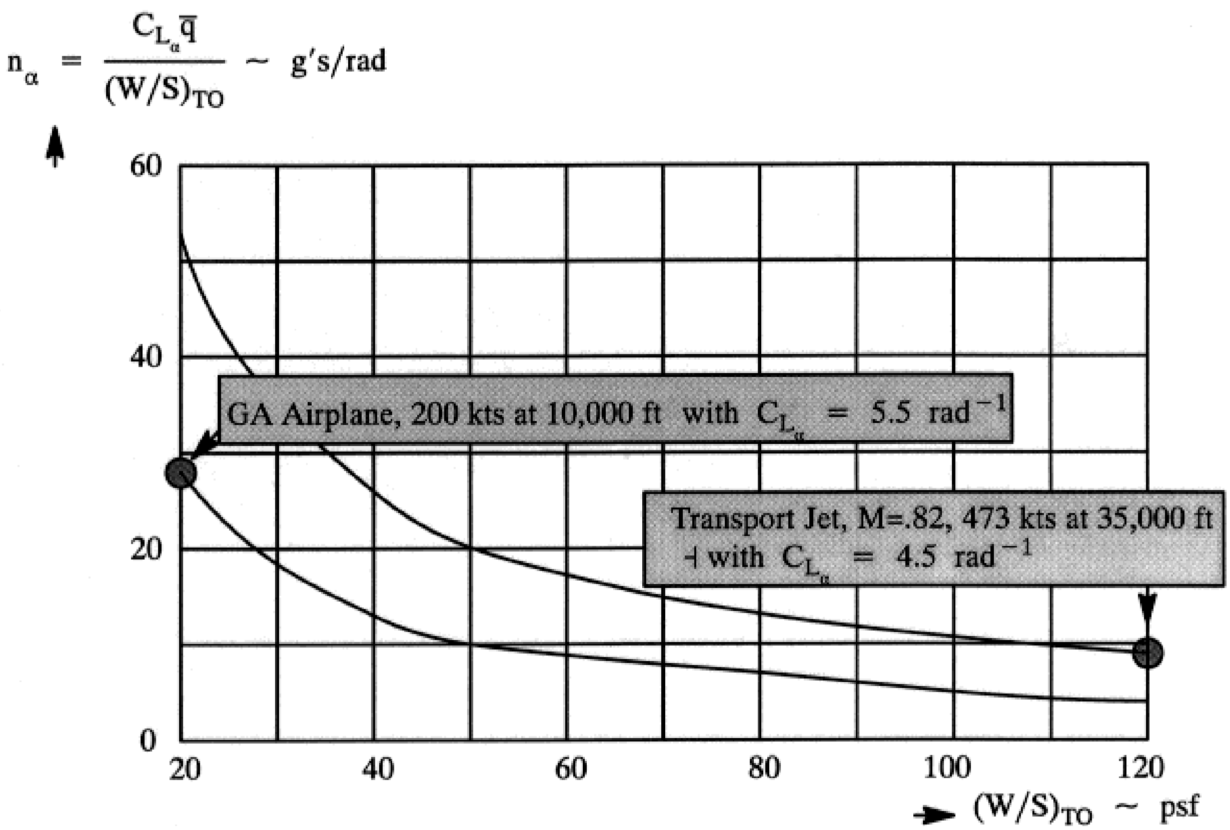


Figure 5 **Ride Quality Comparison Between Jet Transports and Current, Small GA Airplanes**

Obviously, by using the right combination of sensors, computers, actuators and control surfaces the ride of an airplane can be improved. The B1 bomber is a good example of an airplane with a ride augmentation system. However, I believe that it is far more cost–effective to use the inherent good ride quality approach over any systems approach.

7) ALTERNATIVE CONFIGURATIONS

NASA Question:

The ultimate in doorstep–to–destination speed would be vertical flight and/or roadable aircraft configurations. Are there high–payoff/high–risk targets of opportunity we should include in our portfolio? What role should such opportunities play in our SATS Program plan for FY 2001–2008?

Roskam's Response:

Although I certainly support NASA funding for research in the general area of vertical flight and/or roadable aircraft configurations I do believe that noise and systems complexity will continue to be the deathknell for such concepts.

I certainly do not see any role for these ideas in the short term, namely for the SATS Program plan for FY 2001–2008.

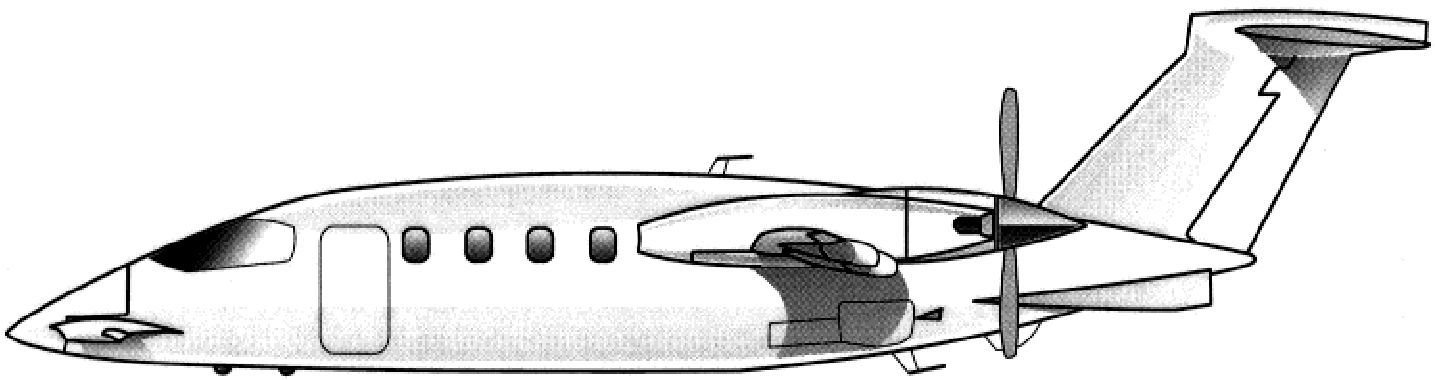
8) SUGGESTIONS?

NASA Question: Are there any other suggestions?

Roskam's Response: Yes, I have four.

I) CONSIDER THREE–SURFACE CONFIGURATIONS

It will be beneficial to take three–surface configurations more serious than has been the case. In terms of achievable trimmed maximum lift coefficient, a properly designed three–surface airplane will always outscore a conventional, tail–aft design. The Piaggio P–180 is still one of the most outstanding aerodynamic designs in production. It also achieves 40% natural laminar flow on the wing and about 10% natural laminar flow on the fuselage. With a simple Fowler flap and a canard trim flap the airplane achieves a maximum trimmed lift coefficient of 2.2.



II) WHATEVER PRODUCT ROLLS OUT, BETTER HAVE SIGNIFICANT VALUE TO THE POTENTIAL CUSTOMER

The personal transportation airplanes envisioned in the SATS program must represent clear value to the customer to be marketable. I suggest that some type of value analysis like the one shown next be included in any design definition studies.

For small, GA airplanes the following value–added parameter (VAP) is suggested as a yardstick:

$$\text{VAP} = \{(\text{DDS})\text{x}(\text{RFPL})\text{x}(\text{Cabinvolume})\} \quad \text{in} \quad (\text{nm/hr})\text{x}(\text{nm})\text{x}(\text{ft}^3) \tag{10}$$

where: DDS is the door–to–destination–speed in kts

RFPL is the range at economical cruising speed with full payload and NBAA reserves in nm

Figure 6 shows an example plot of this VAP parameter for a range of business airplanes plotted versus their market price. The data were modified from Ref. 3. It is clear that some airplanes offer more value for the money than others. In turn it may be rational to use such a plot to determine desirable (i.e. marketable) design characteristics for the new family of airplanes.

To that end the lower part of Figure 6 has been replotted in Figure 7 and the trend line has been linearized in two segments. Data for single engine and twin engine turboprop airplanes have also been added. It is clear that when designing a small business jet airplane the competition from single engine turboprop airplanes must be carefully considered. Note that the twin–engine turboprops compare rather poorly with their single engine counterparts when using this VAP parameter.

From a value–to–the–customer viewpoint, Figure 7 shows that the airplanes to beat are the Pilatus PC–12 and the Aerospatiale TBM 700. For a six–passenger personal transportation jet to be effective in the market place requires a value of $\text{VAP} \approx 50$. Assuming a minimum required DDS of 200 kts and a ratio of $\Delta R_{ground}/R_{block} = 0.10$ results in a design cruise speed of about 300 kts. In an airplane without sanitary facilities a design range with full payload of 900 miles is probably about right in view of the "bladder–time" phenomenon. With a VAP of 50 this results in a required cabin volume of about 185 cu.ft. It is noted that this is about the cabin volume of a Cessna Citationjet. This airplane has a RPFL of 769 nm and a cruise speed of 311 kts.

The challenge therefore is to design such a small twinjet for a price of 1.5 to 2 million dollars. In addition to having an acceptable VAP value, a general aviation airplane has real value to a non–pilot customer if the airplane provides reliable and affordable transportation while at the same time providing a convenient place to work when airborne. If the airplane is to be a convenient place to work then it must be equipped with appropriate communications and lap–top plug–in facilities. All this implies that the airplane itself must be easy to operate, in other words: user–friendly. **That aspect of airplane design is being addressed as part of the AGATE program.**

Table 3 presents a mission specification for the proposed family of airplanes.

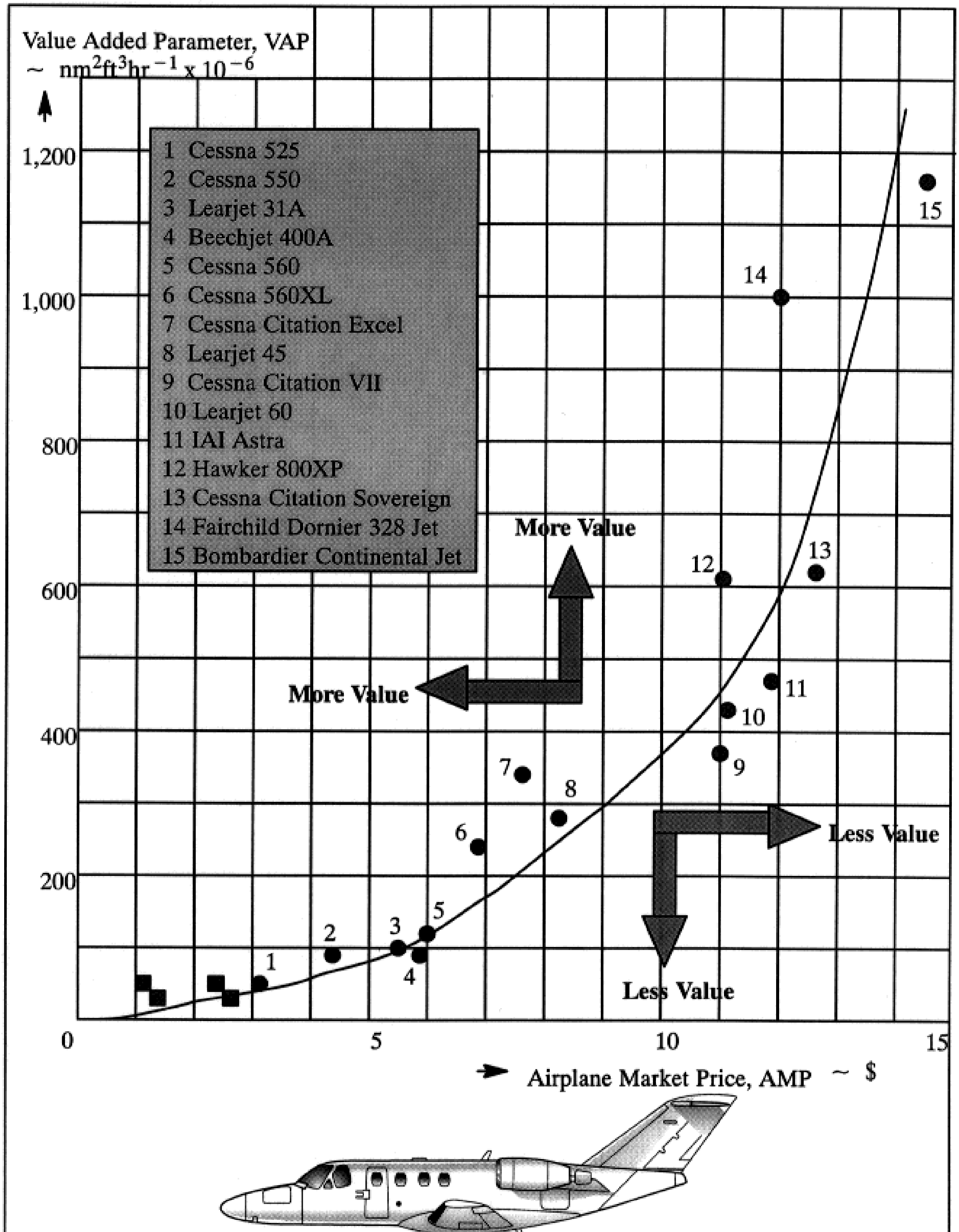


Figure 6 VAP (Value-added-parameter) as a function of Airplane Market Price

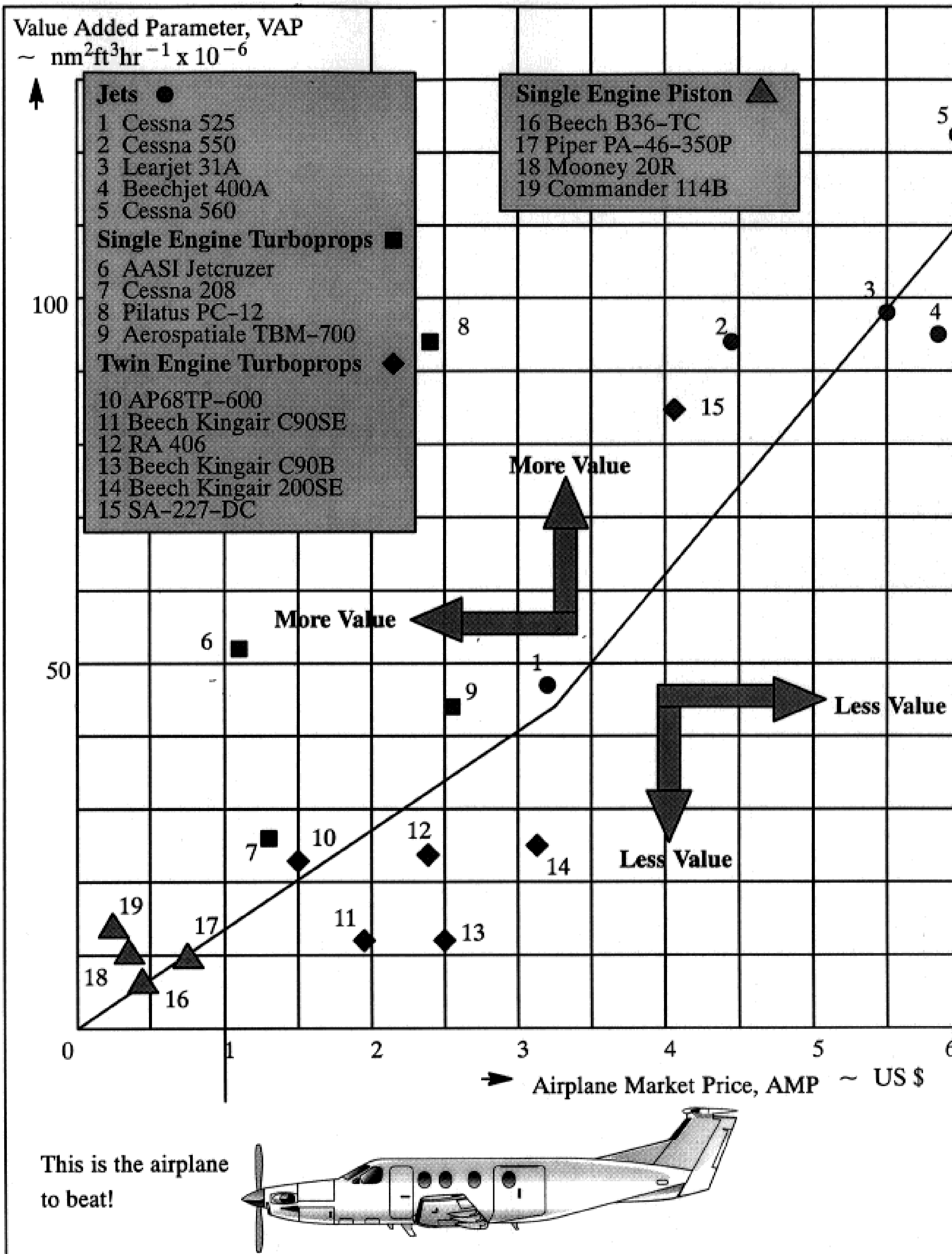


Figure 7 VAP (Value-added-parameter) as a function of Airplane Market Price

Cost savings in the manufacturing of the airframe must be realized. The author believes that this can be accomplished this by designing a large amount of commonality in a family of two airplanes: with 4–seat and 6–seat accommodations and by reducing the parts–count.

For easy reference these airplanes will be referred to as the Jayhawk–400 and Jayhawk–600 respectively. These airplanes will be designed to have aerodynamically common wings, aft fuselage, empennage as well as a common avionics/flight management and control system, common flight control actuators and common components in many other systems. Such commonality and the incorporation of automated aluminum bonding techniques should allow for a 40% reduction in manufacturing and engineering manhours.

The following areas of commonality have been identified as a result of several design studies carried out by the author's students:

* the same wing torque–box and carry–through structure
* as much commonality in the wing leading and trailing edge as practical
* the same fuselage, except for length
* the same empennage
* the same landing gear
* as much commonality in the propulsion installation as practical
* the same flight control systems
* the same basic fuel system
* the same electrical system **(no hydraulic system, period!)**

In terms of their external appearance the Jayhawk 4 and Jayhawk 6 will differ primarily in the length of the fuselage. Figures 6 and 7 show several candidate configurations which have evolved from student design studies. The airplane of Figure 6 is being developed by Mr. Charles Svoboda, a doctoral student. The airplane of Figure 7 was developed by a small team of undergraduate students.

Table 3 Mission Specification for a Proposed Family of Personal Transportation Airplanes

Payload: Version 1: 4 Persons, 175 lbs each plus 20 lbs of baggage
Version 2: 6 Persons, 175 lbs each plus 20 lbs of baggage

Crew: Single pilot operation is required

Performance desired for each version:

		Version 1: 4–place	Version 2: 6–place
Range:	Still air range with reserves equal to 20 percent of mission fuel and a full payload	600 nm	800 nm
Speed:	Cruise:	M = 0.58 at 25,000 ft	M = 0.65 at 30,000 ft
	Stall speed of	61 kts	61 kts
		at a landing weight of 90% of the take–off weight	

Fieldlength: Both versions at max. t.o. weight
Take–off: 3,000 ft under sea–level, 109 deg F. conditions
Landing: 2,500 ft under sea–level, 109 deg F. conditions at a landing weight of 90% of the take–off weight

		Version 1	Version 2
Climb:	Service ceiling:	25,000 ft	30,000 ft
	Direct climb to service ceiling:	20 min.	20 min.
Maneuvering:	Perform 20 degree banked, sustained turns at 'begin cruise' weight and at:	30,000	30,000 ft
Powerplants:		One Agate 99–1 turbofan	Two Agate 99–1 turbofans
Pressurization:	8,000 ft cabin at:	30,000 ft	30,000 ft

Certification: FAR 23

Mission Profile:

1) Engine start and warm–up
2) Taxi
3) Takeoff
4) Climb to 30,000 ft
5) Cruise
6) Descent
7) Landing, taxi, shutdown (20% of mission fuel left as reserves)

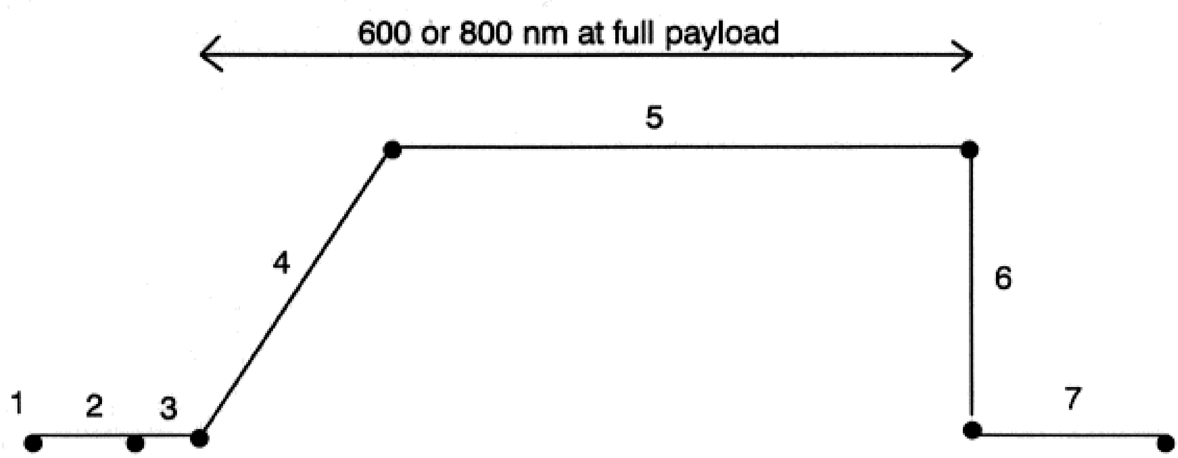
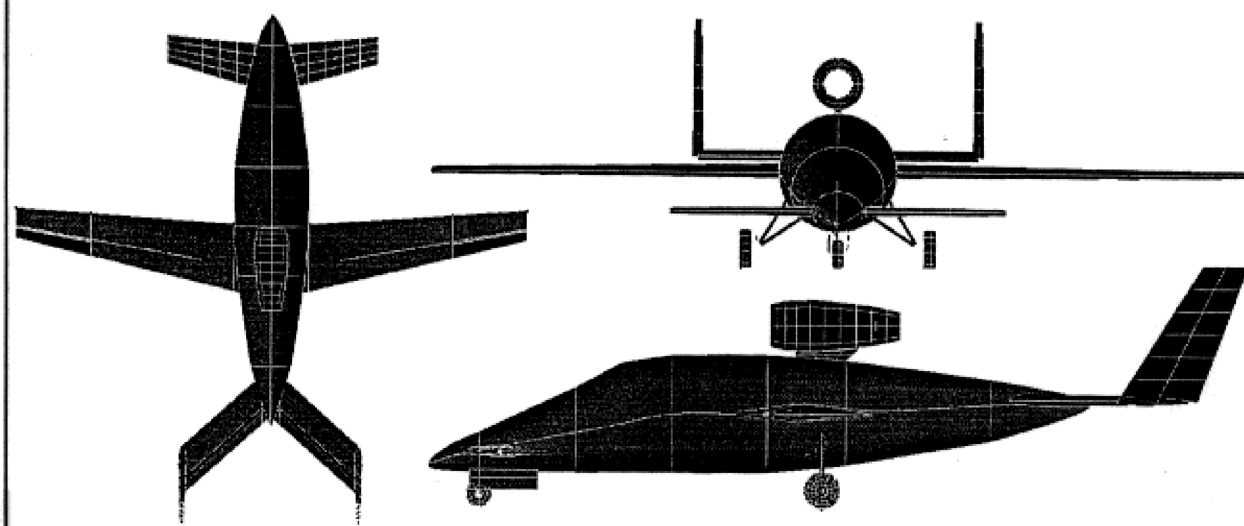
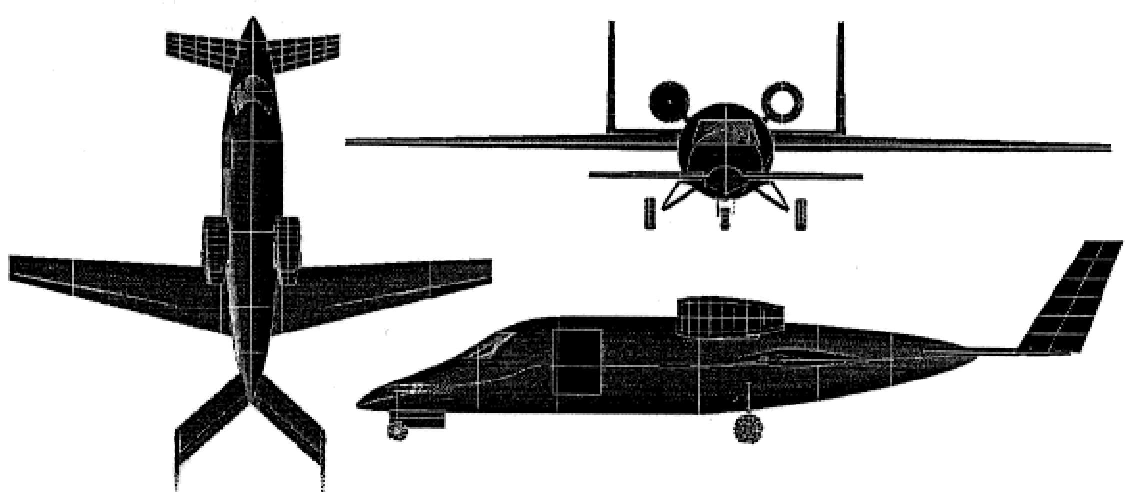


Figure 6 Perspective Drawing of the Svoboda Jayhawk 6



Jayhawk 4



Jayhawk 6

Figure 7 **Three-views of the Jayhawk 4 and Jayhawk 6 as Evolved by a Team of Undergraduate Students**

III) SMALL REGIONAL JET TRANSPORTS

Except for Fairchild–Dornier, no US manufacturer has entered the 32–70 regional passenger jet market. It will be shown that there is a significant market opportunity for 10–22 passenger jets.

To that end, consider Figure 8 which relates the value factor, VF, of a regional transport to its airplane market price, AMP.

The value factor, introduced by Norris in Ref.4, is defined as follows:

$$VF = \frac{SMD \times CFP \times PH}{FBD} \quad (11)$$

where: SMD is the number of seat–miles that are generated per day

CFP is the cubic feet of available space per passenger

PH is the passenger headroom in ft

FBD is the fuel burn in lbs per day

Note that for airplane market prices (AMP's) above $ 8 million the turboprops enjoy a much higher value factor than the jets. Despite this, regional jets are now rapidly replacing regional turboprops in this market. In fact, many regional turboprop production lines have already been shut down. Reasons for this trend are noise and vibration as well as the perceived higher level of safety. All these factors favor jets over turboprops. Yet, none of these factors are included in the value factor, VF.

What is really interesting is that the graph shows that jets would enjoy a VF advantage over turboprops in the price range below 8 million USD. That is the expected price range for 9–19 passenger regional jets. Since there are currently no jet airplanes in this category there seems to be a definite market opportunity waiting to be exploited. If this opportunity is to be realized, the cost per airplane must be kept down!

Figures 9 and 10 show perspective renditions of a 10–pax and 22–pax regional jet which embody a large amount of commonality. These airplanes were evolved by one of the author's students, Mr. How Mein.

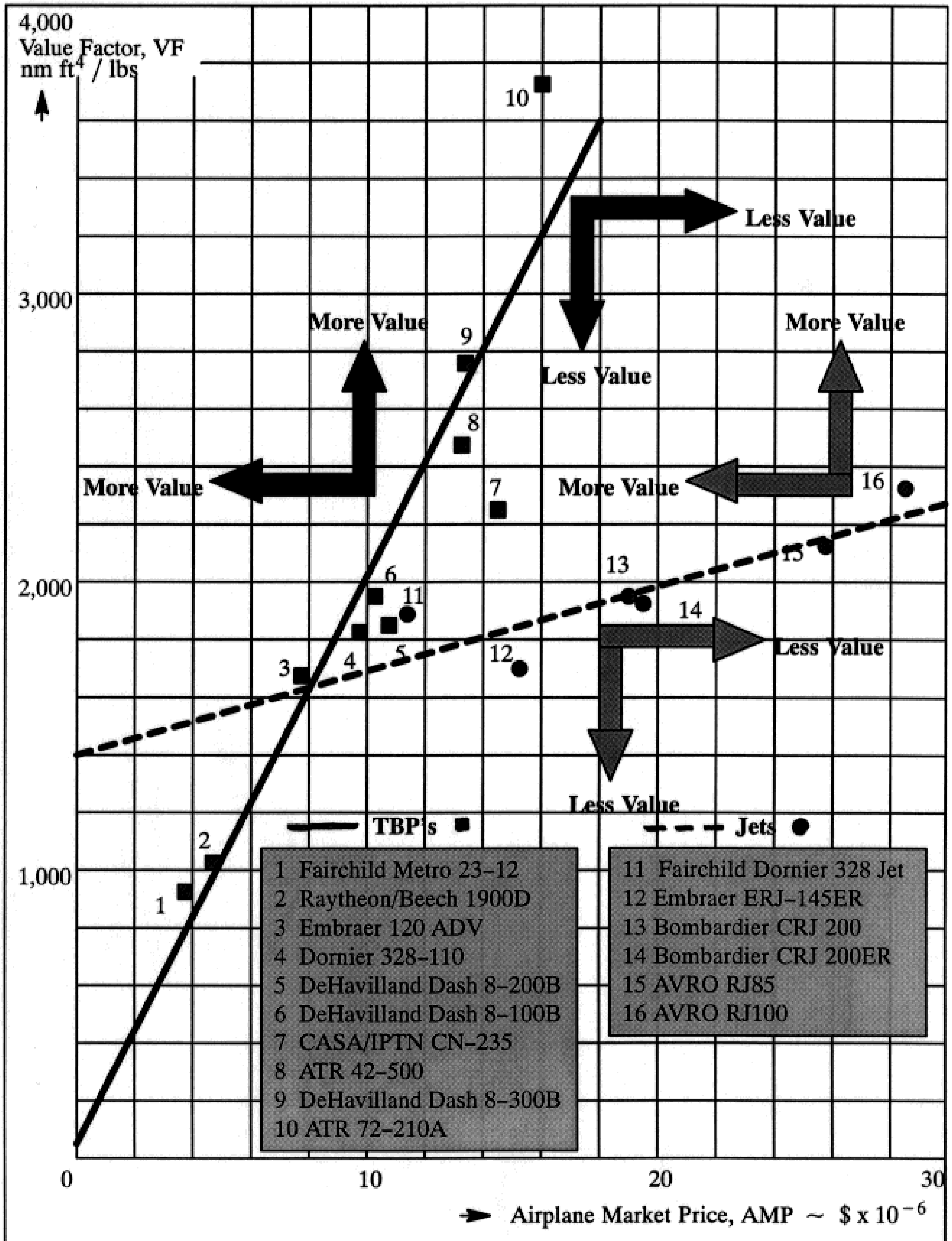


Figure 8 VF (Value Factor) as a function of Airplane Market Price

Figure 9 Perspective Drawing of a 10-Passenger Regional Jet as Evolved by Mr. How Mein, K.U. Graduate Student

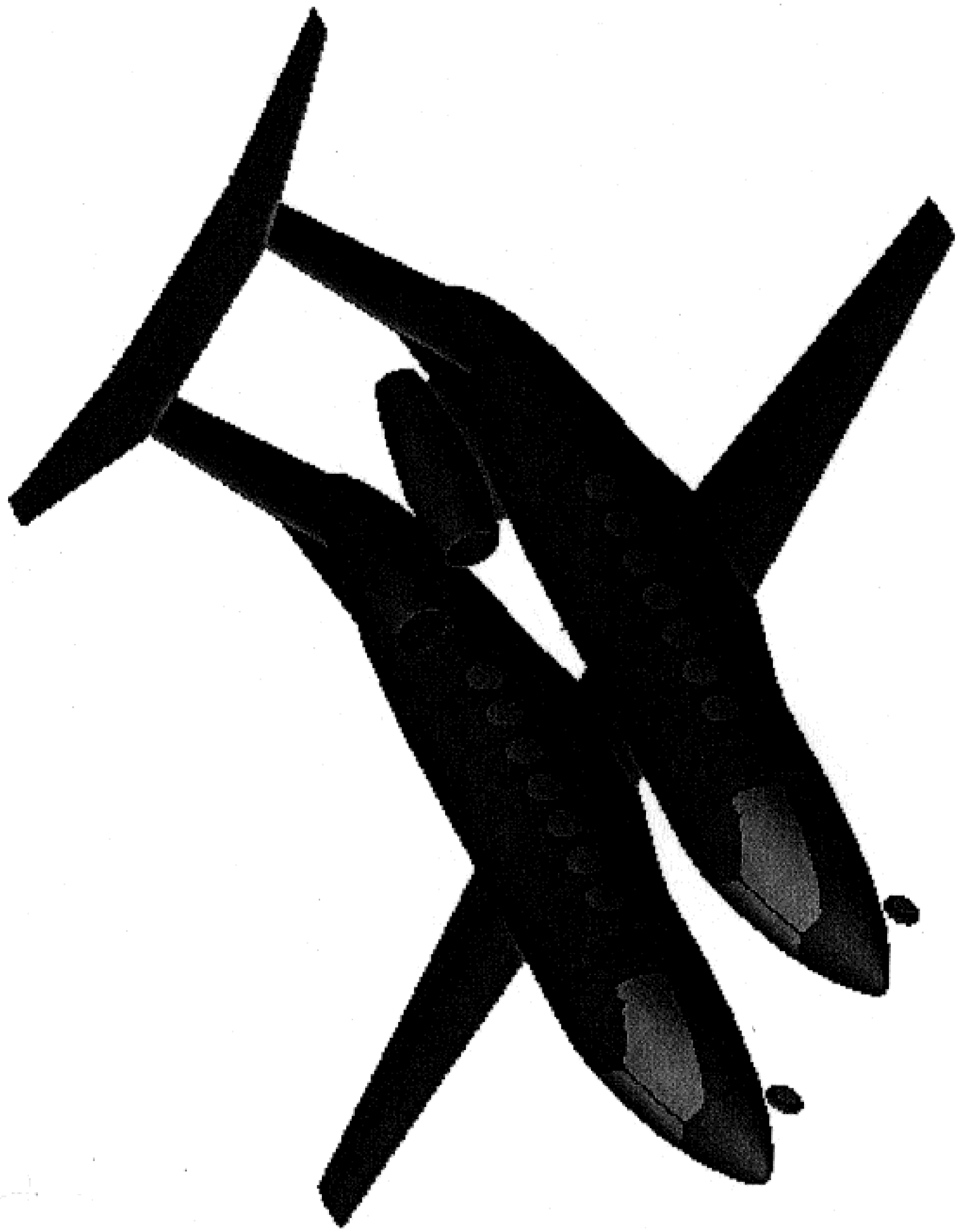


Figure 10 **Perspective Drawing of a 22–Passenger Regional Jet as Evolved by Mr. How Mein, K.U. Graduate Student**

IV Airworthiness and Certification Issues for SATS Airplanes

Current FAR 23 certification standards do not address the type of highly augmented airplanes envisioned in this paper. To avoid the need for extensive "pilot training" all flight crucial systems must be designed without the conventional approach of a mechanical control system back-up. A major question is the decision on the level of redundancies required. In commercial transports the 10-9 criterion is used to establish the required level of redundancy. In airplanes with hydraulic flight controls commanded with digital computers this normally leads to a requirement for three independent systems.

It is proposed to establish the required level for FAR23 airplanes based on an acceptable fatal accident number.

GAMA (General Aviation Manufacturers Association) statistics show that in the USA there are on the average 2 fatal accidents per 100,000 flying hours.

The total number of GA flying hours per year is about 30,000,000. That translates into 600 fatal accidents per year. This accident rate (although very poor compared to commercial transport jets) is apparently acceptable to those people wishing to fly on GA airplanes.

It is observed that less than 10% of the GA accidents are systems related. The majority causes have to do with pilot ineptness, lack of training and often just plain sloppiness.

It is proposed that as a design criterion 1 fatal accident (due to systems related causes) per 10,000,000 flying hours be used. That is a factor 50 better than the currently acceptable fatal accident rate.

To limit the required systems redundancy to two independent systems translates into a failure probability of 1:3,163 per system-hour. It is the author's contention that this is a do-able proposition with existing commercially available hardware. However, it will be necessary to conduct realistic experiments to demonstrate this capability for certification purposes.

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