SOME LANDING-GEAR CONSIDERATIONS FOR SPACE SHUTTLE VEHICLES

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INTRODUCTION

Landing of the space shuttle vehicles probably causes less concern to planners than any of the other operational phases - launch, staging, orbit, reentry, flyback, and ground operations. It is generally accepted that the shuttle vehicles will land like aircraft on conventional runways. Since aircraft are currently in operation which have landing weights in the same ranges as the shuttle orbiter and booster, design of landing gear would appear to be a relatively minor problem. However, the importance of landing-gear design should not be underestimated because it is fundamental to the basic concept of the space shuttle, that is, a vehicle which returns safely to ground to be used again. Any shuttle vehicle, no matter how successful otherwise, is a failure if it does not land safely.

Although shuttle vehicles land like aircraft, they are, in fact, hybrid launch vehicle/aircraft and spacecraft/aircraft. There are many differences that affect landing-gear design. Landing-gear weight compared with payload weight is very high; the potential for high temperature exposure of tires is great; landing weight of the booster is large, even for aircraft; increased landing-gear maintenance can be tolerated; design life is shorter; and the cost in both money and notoriety for a landing mishap may be high. Since there are many differences between the shuttle vehicles and conventional aircraft, the possible advantages in new-technology landing gear should be considered in the planning stages.

LANDING CONDITIONS

(Slide 1)

Landing conditions for space shuttles are much the same as for any aircraft with the exception of abort. A critical factor in landing gear design for normal conditions will probably be braking performance on wet and/or icy runways. In an emergency almost any conceivable landing site may be possible but some, such as short runways, water, or rough surfaces may be considered likely. In abort, whether the landing gear can function at all depends greatly on the amount of excess load on board and the location of the vehicle center of gravity. Ideally, for normal landing, the best possible landing system would be one which is left on the ground, a landing sled or some sort of "superfoam" runway, for example. The perfect emergency landing system would permit landing anywhere, from mountain peak to ocean surface, but would probably constitute the major portion of vehicle weight. Somewhere in between a compromise system which provides reasonable landing flexibility at an acceptable weight penalty must be found. The relative importance of each of these factors must be realistically assessed in making a decision.

LANDING CONDITIONS

NORMAL

- DRY RUNWAY
- WET RUNWAY
- ICY RUNWAY

EMERGENCY

- SHORT RUNWAY
- WATER
- ROUGH SURFACE

ABORT

- ANY OF ABOVE WITH EXCESS LOAD

Slide 1

REQUIREMENTS AND CONSTRAINTS

(Slide 2)

The requirements and constraints on shuttle landing gear are, like landing conditions, much the same as for any aircraft. However, they are more severe in several instances. The cost per unit weight for landing gear is much higher for the shuttle. The possibility of high temperature exposure may require refrigeration or additional insulation around the landing-gear storage compartments. Fail-safe deployment and take-off capability are standard requirements but cross-wind landing stability may be a critical factor because of the size and unusual geometry of shuttle vehicles. Any landing-gear system must reasonably satisfy all these requirements and constraints.

REQUIREMENTS AND CONSTRAINTS

LOW WEIGHT

POSSIBLE HIGH-TEMPERATURE EXPOSURE

FAIL-SAFE DEPLOYMENT AND OPERATION

TAKE-OFF CAPABILITY FOR FERRYING

CROSS-WIND STABILITY

Slide 2

LANDING—GEAR TYPES

(Slide 3)

There are several different types of landing gear systems which could be used on shuttle vehicles. Conventional pneumatic tire landing gear with servo—controlled antiskid braking is the current most likely candidate. However, for reasons to be discussed later in this paper, some other types may offer certain advantages. Candidates are conventional systems with metal or wire brush wheels replacing pneumatic tires, skids with auxiliary take—off gear for ferrying, either type of wheeled system with skid brakes, and air-cushion landing systems (ACLS).

LANDING-GEAR TYPES

CONVENTIONAL WHEEL WITH TIRE } ANTISKID BRAKES
METAL OR WIRE BRUSH WHEELS }

SKIDS

WHEEL AND TIRE WITH SKID BRAKES

AIR CUSHION WITH SKID BRAKES

Slide 3

CONVENTIONAL WHEEL AND TIRE

(Slide 4)

A conventional wheel and pneumatic-tire landing gear with a servo-controlled antiskid braking system represents a state-of-the-art approach to shuttle landing gear. This is one of its most attractive features in that it is a proven system and development time and costs should be minimal. Such systems have shown excellent dry runway braking and they are amenable to using gravity-drop emergency deployment. However, there are shortcomings to conventional gear. The rubber compounds usually used in tires tend to revert to their uncured state at about 150°C (300°F). Braking performance on wet runways is much poorer than on dry runways because even the best antiskid system can only give the maximum friction available to it. At landing speeds on a wet runway this available friction is very low as will be shown later. Emergency landing on water, which is probably the single most likely emergency landing site, is not possible. Impact loads on landing are transmitted to the fuselage at "points" which places large moments on the structure. Landing impact loads will be a major factor in longitudinal structural stiffness design. Finally, cross-wind landing stability is solely a function of tire side-force limits unless a rotation capability is designed into the landing gear at a weight and complexity penalty.

Replacing the pneumatic tire on conventional gear with a metal wheel or a wire brush wheel (similar to the brush wheel on a grinding machine) may eliminate the temperature problem and possibly the wet runway braking problem. However, acceptable designs and materials must be developed and more compliance is needed in struts to absorb landing and roll-out loads.

CONVENTIONAL WHEEL AND TIRE

ADVANTAGES

- CURRENT TECHNOLOGY
- GOOD DRY RUNWAY PERFORMANCE
- SIMPLE EMERGENCY DEPLOYMENT

DISADVANTAGES

- TEMPERATURE LIMITS ON TIRES (MAY NEED REFRIGERATION)
- POOR WET AND ICY RUNWAY PERFORMANCE
- NO WATER-LANDING CAPABILITY
- POINT LOADS ON STRUCTURE

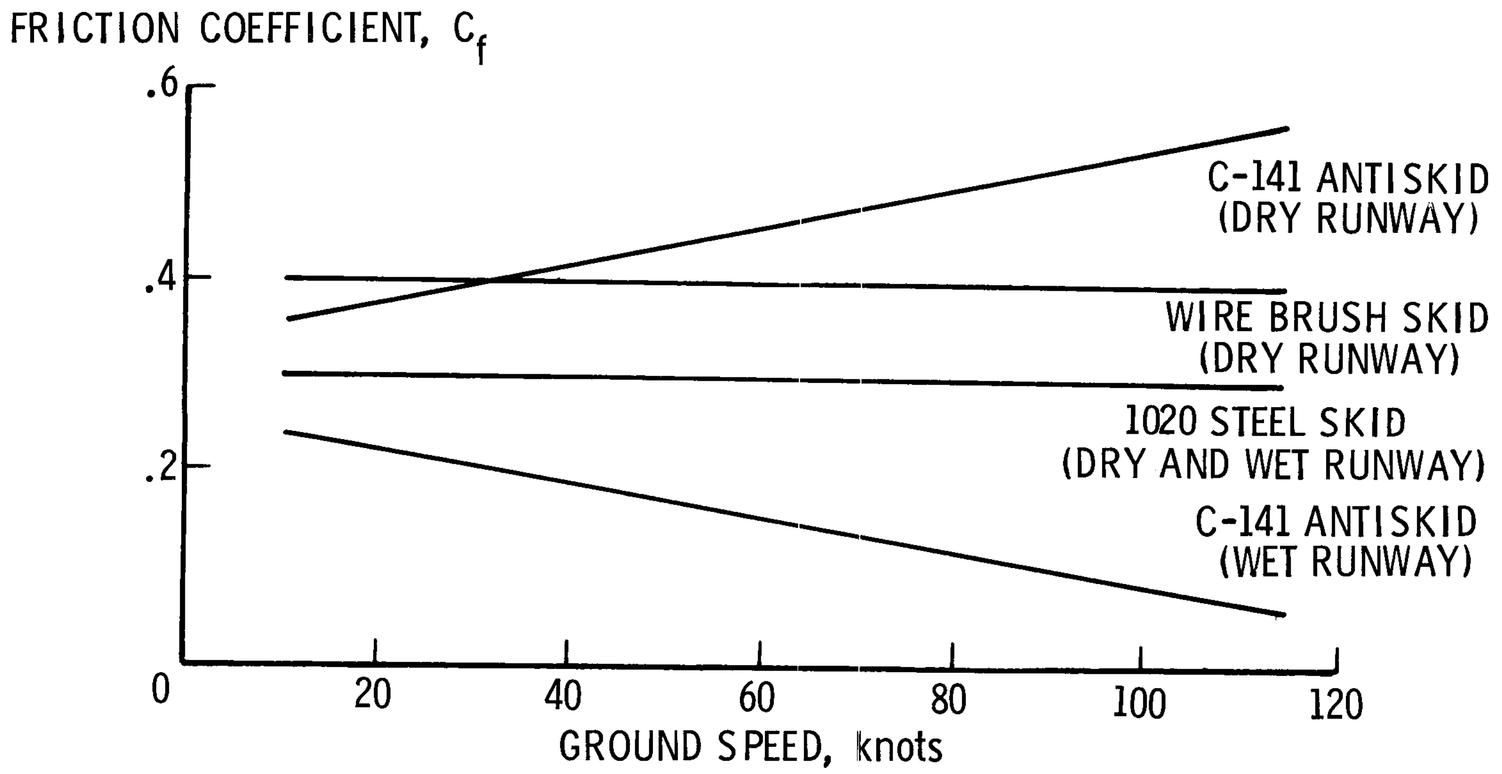
Slide 4

BRAKING-SYSTEM FRICTION COEFFICIENTS

(Slide 5)

As mentioned earlier, antiskid braking systems do not give very good braking performance on wet runways. Another landing system, a skid system, often mentioned for high-temperature applications does not have this problem. This slide shows a comparison of typical friction coefficients for a C-141A transport aircraft with those for some experimental skids on wet and dry runway surfaces. These coefficients, measured by researchers from Langley Research Center (refs. 1 and 2), will vary with runway surface and aircraft design but are representative of what may be expected. The C-141A gives excellent dry runway braking but its wet runway performance is poor. In fact, the braking distance corresponding to these curves is over twice as long for the wet runway. Brake friction for the 1020 steel skid, however, is unaffected by the wet runway. Although the dry runway performance is not as good as for the antiskid system, the runway needed to assure safe landing can be much shorter since the wet case is the limiting situation. A wire brush skid, made of 5-cm (2-inch) lengths of wire rope welded to a base plate, gives even better performance on a dry runway. No wet or icy runway braking tests have been run on wire brush skids but, intuitively, they would appear to be better than solid skids under these conditions.

BRAKING-SYSTEM FRICTION COEFFICIENTS



Slide 5

SKIDS

(Slide 6)

Skid landing systems for shuttle vehicles have some attractive advantages. They are insensitive to temperature, give good wet runway (and possibly icy runway) braking, and are mechanically simple. Insufficient data on skid performance at various bearing pressures make weight estimates difficult, but savings in insulation and mechanical systems may make them attractive from a weight standpoint. The data shown on the previous slide were for a bearing pressure of 150 kN/m^2 (22 psi), but if 280 kN/m^2 (40 psi) or 410 kN/m^2 (60 psi) could be used, skid area would be reasonable.

The disadvantages of skids for shuttle applications are several. Skids with directional control have not been developed. Take-off for ferrying would require auxiliary wheels, possibly installed after landing and removed for launch. Shock absorbers which are not affected by high temperatures would have to be used and they would need more stroke than in a conventional system where tires take part of the landing impact. Landing on water could conceivably be accomplished by hydroplaning but research would be needed to evaluate this capability. Finally, the ride and structural loads on the runway would be more severe than with conventional gear without some sort of suspension system.

SKIDS

ADVANTAGES

- UNAFFECTED BY TEMPERATURE
- GOOD WET RUNWAY PERFORMANCE
- EMERGENCY DEPLOYMENT SIMPLE

DISADVANTAGES

- NO DIRECTIONAL CONTROL
- FERRYING REQUIRES AUXILIARY TAKE-OFF GEAR
- HIGH-TEMPERATURE AND HIGH-ABSORPTION SHOCKS NEEDED
- WATER LANDING QUESTIONABLE
- ROUGH RIDE ON RUNWAY

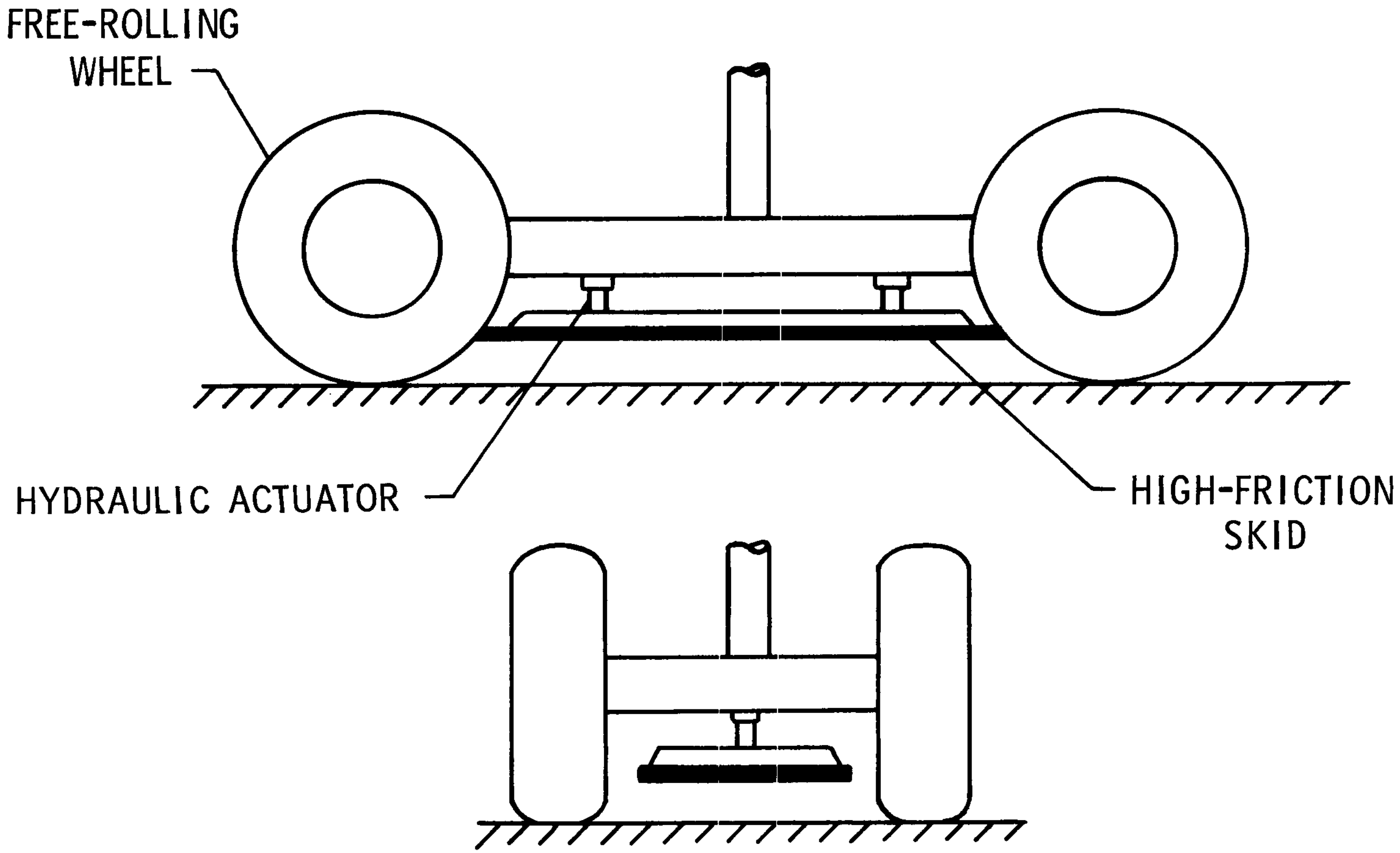
Slide 6

WHEEL AND SKID SYSTEM – DESCRIPTION

(Slide 7)

An unconventional compromise system which offers some of the advantages of both skids and wheels is shown in this slide. It uses a standard wheel bogey with free-rolling wheels and hydraulically operated skid brakes. The all-weather braking performance and passive operation simplicity of skids are maintained but directional stability, cornering force, ferrying ability, and impact and roll-out cushioning are provided by tires. Since part of the aircraft weight is supported by the tires for directional control during braking, some reduction in skid effectiveness occurs. Probably no more than 15 percent of the aircraft weight would be needed on the tires. A skid having a high friction coefficient (coefficients approaching 0.6 have been obtained experimentally) could easily compensate for this loss.

WHEEL AND SKID SYSTEM



Slide 7

WHEEL AND SKID SYSTEM – ADVANTAGES AND DISADVANTAGES

(Slide 8)

The good all-weather runway braking performance of the wheel and skid system while maintaining directional stability and cornering force is its most obvious advantage. However, some less obvious advantages should be explored in a comprehensive study of this system. For example, elimination of the braking function from tires may allow the use of higher temperature materials and/or lighter weight construction. Emergency deployment is the same as with conventional systems.

The wheel and skid combination shares some of the disadvantages of the separate systems. The tires will be temperature limited although the limits may be raised somewhat and the fuselage will be loaded at points. Water landing by hydroplaning is possible but questionable. Cross-wind landing requires either full skid deployment to take side loads off the tires, if the vehicle is angled into the effective wind direction, or unloading of the brakes to put more weight (and, hence, side friction force) on the tires if the vehicle heads directly down the runway. One of the biggest disadvantages is that it is a new-technology system and would require much development research on both skids and the system itself.

WHEEL AND SKID LANDING GEAR

ADVANTAGES

- GOOD WET RUNWAY PERFORMANCE MAINTAINING CORNERING CAPABILITY
- BRAKING ELIMINATED FROM TIRE DESIGN (POSSIBLE TEMPERATURE AND WEAR ADVANTAGES)
- EMERGENCY DEPLOYMENT SIMPLE

DISADVANTAGES

- TEMPERATURE LIMITS ON TIRES
- NEW TECHNOLOGY REQUIRED
- POINT LOADS ON STRUCTURE
- NO WATER LANDING

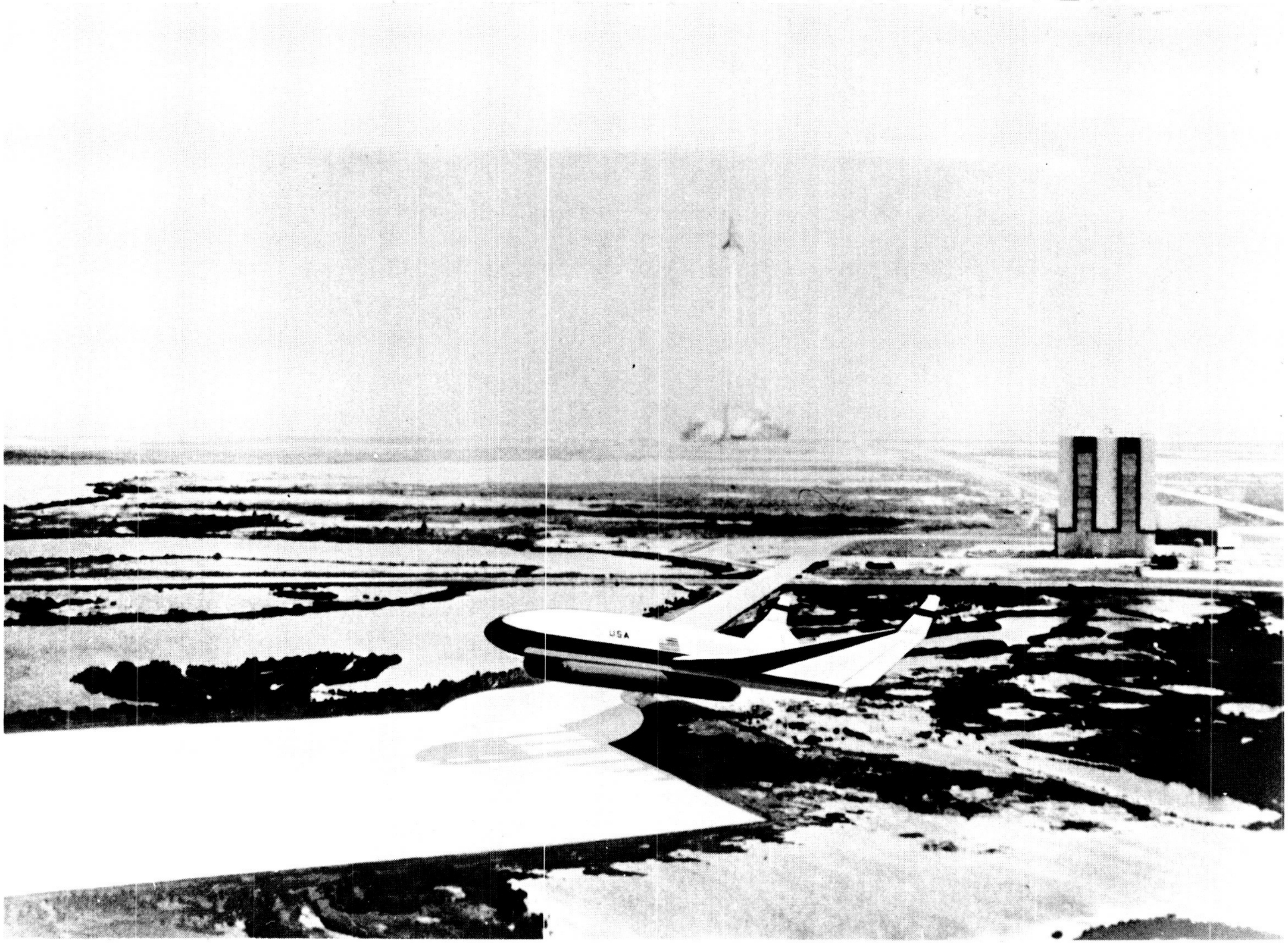
Slide 8

SHUTTLE AIR–CUSHION LANDING SYSTEM

(Slide 9)

One candidate landing–gear system for shuttle applications, the air–cushion landing system (ACLS), is very unconventional. The figure shows an artist's conception of an ACLS on a delta–winged booster. It is essentially a ground effects machine attached to the bottom of the fuselage. This system was developed by Bell Aerospace Company (ref. 3) and has been flight tested on a small lightweight airplane.

SHUTTLE AIR-CUSHION LANDING SYSTEM



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AIR-CUSHION LANDING SYSTEM – OPERATION

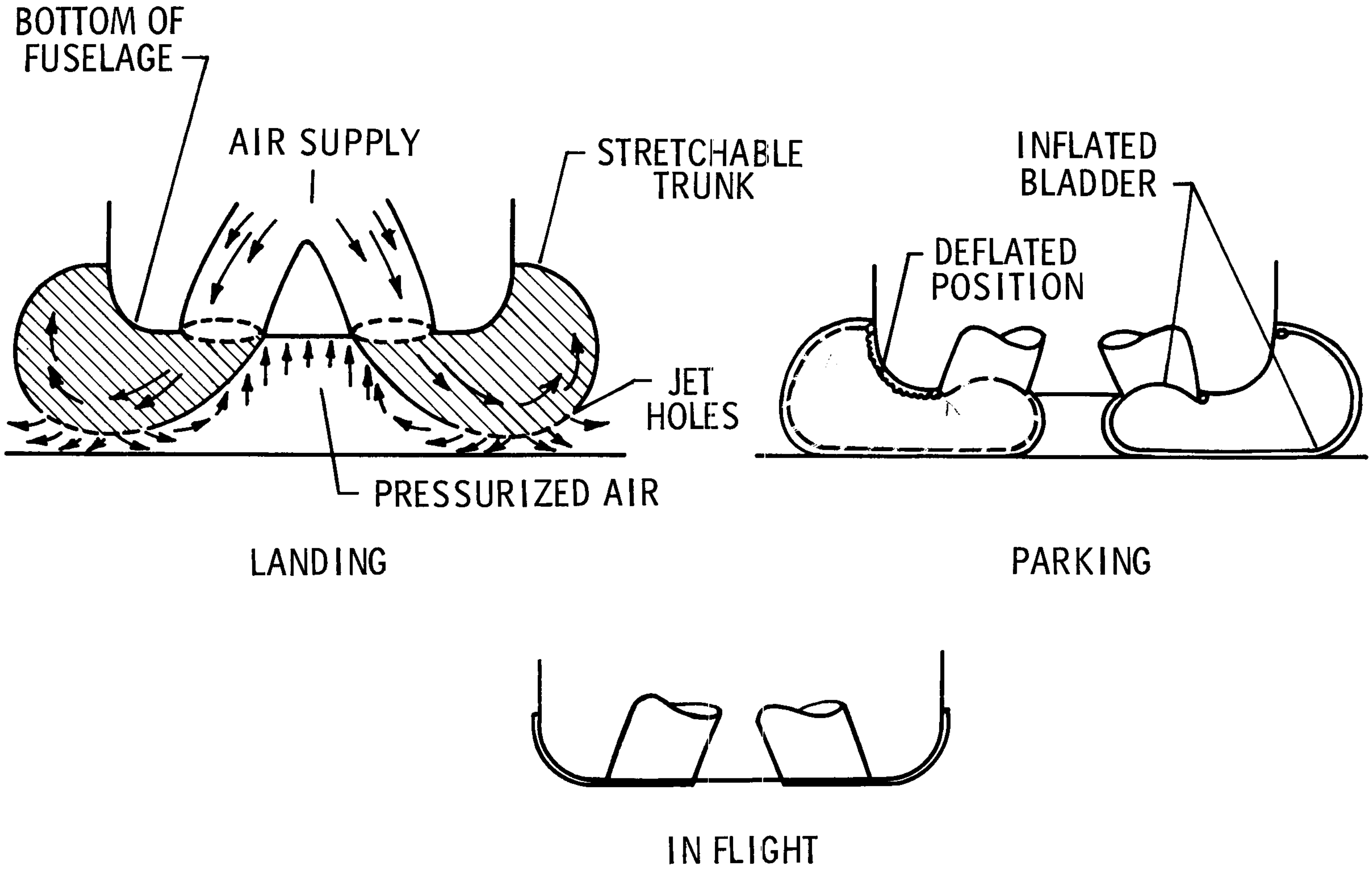
(Slide 10)

The ACLS operating principle is shown in the upper left sketch. A large flexible trunk is attached to the fuselage in an elongated toroid shape. Air is supplied to this trunk by an on-board supply and escapes through small holes in the bottom of the trunk. The escaping air has two functions: it lubricates the cushion to provide vertical support and prevent scuffing; and it pressurizes the air trapped inside the toroid. A combination peripheral jet/plenum type air cushion is the result. The pressurized trunk provides energy absorption during landing impact. Inflation pressures in the trunk can be relatively low, about 14 to 28 kN/m^2 (2 to 4 psi), and the footprint pressure is about one-half that.

Parking or flotation is accomplished with the use of the inflatable bladder arrangement shown in the upper right sketch. This bladder simply seals the jet holes and air supply holes and retracts against the fuselage when not in use.

During flight the ACLS trunk, which is made of a stretchable material, also retracts against the fuselage as shown in the bottom sketch. The trunk can be covered with doors, if needed, or simply be left exposed if conditions permit.

AIR-CUSHION LANDING SYSTEM



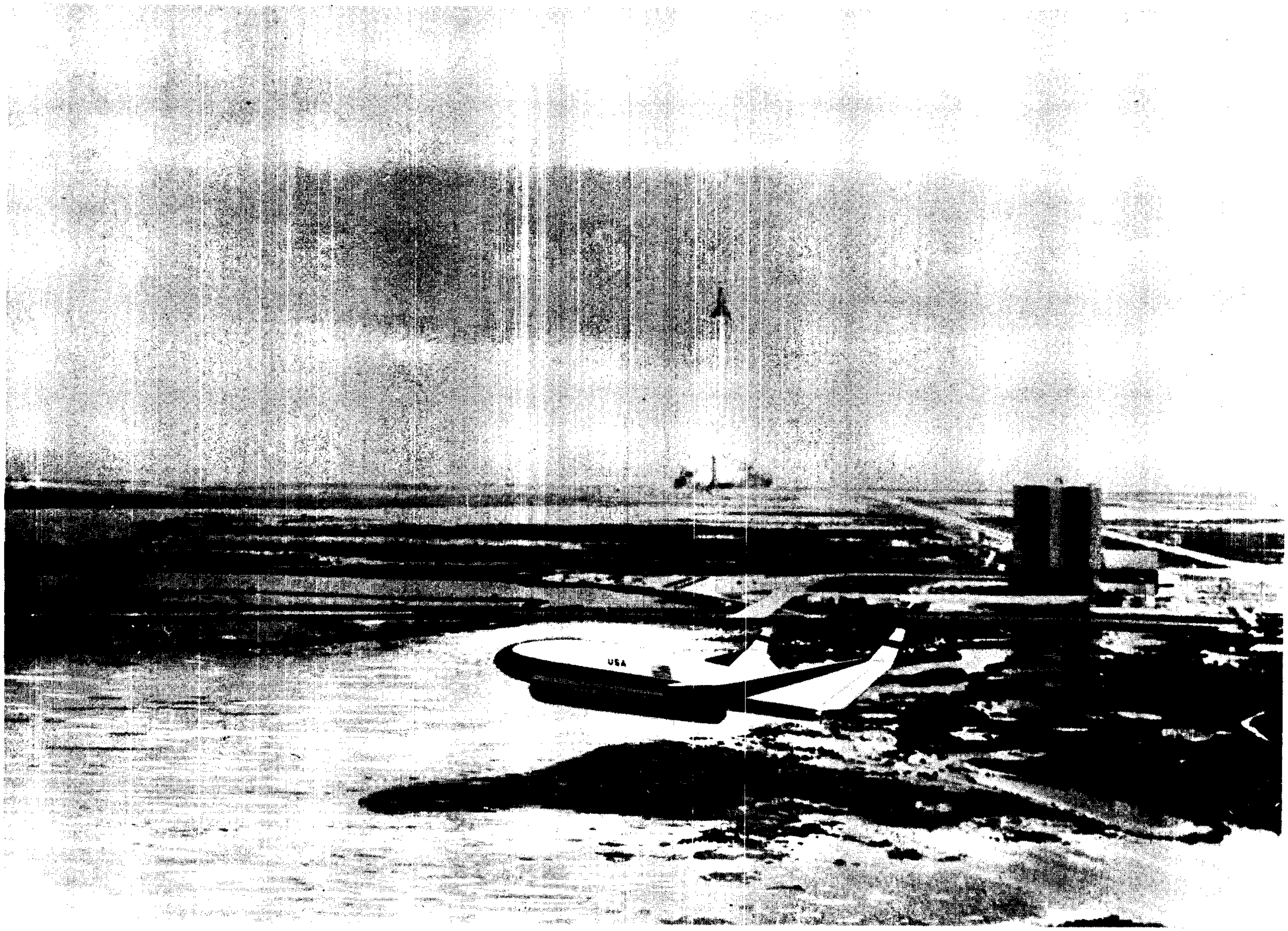
Slide 10

AIR CUSHION – WATER LANDING

(Slide 11)

Since the ACLS is a ground-effects-type device, it has some of the features of the ground effects machine. One of the more interesting, shown here, is water landing. This capability has been demonstrated with the small demonstration plane as has water take-off, water-to-land transition, and rough-field landing and take-off. The only limiting factor for both water and rough-field landing is wave length and height relative to the air-cushion length and trunk depth. The ACLS also has a large cross-wind landing capability as the vehicle can simply head into the resultant wind at an angle to the landing direction.

WATER LANDING WITH AIR CUSHION



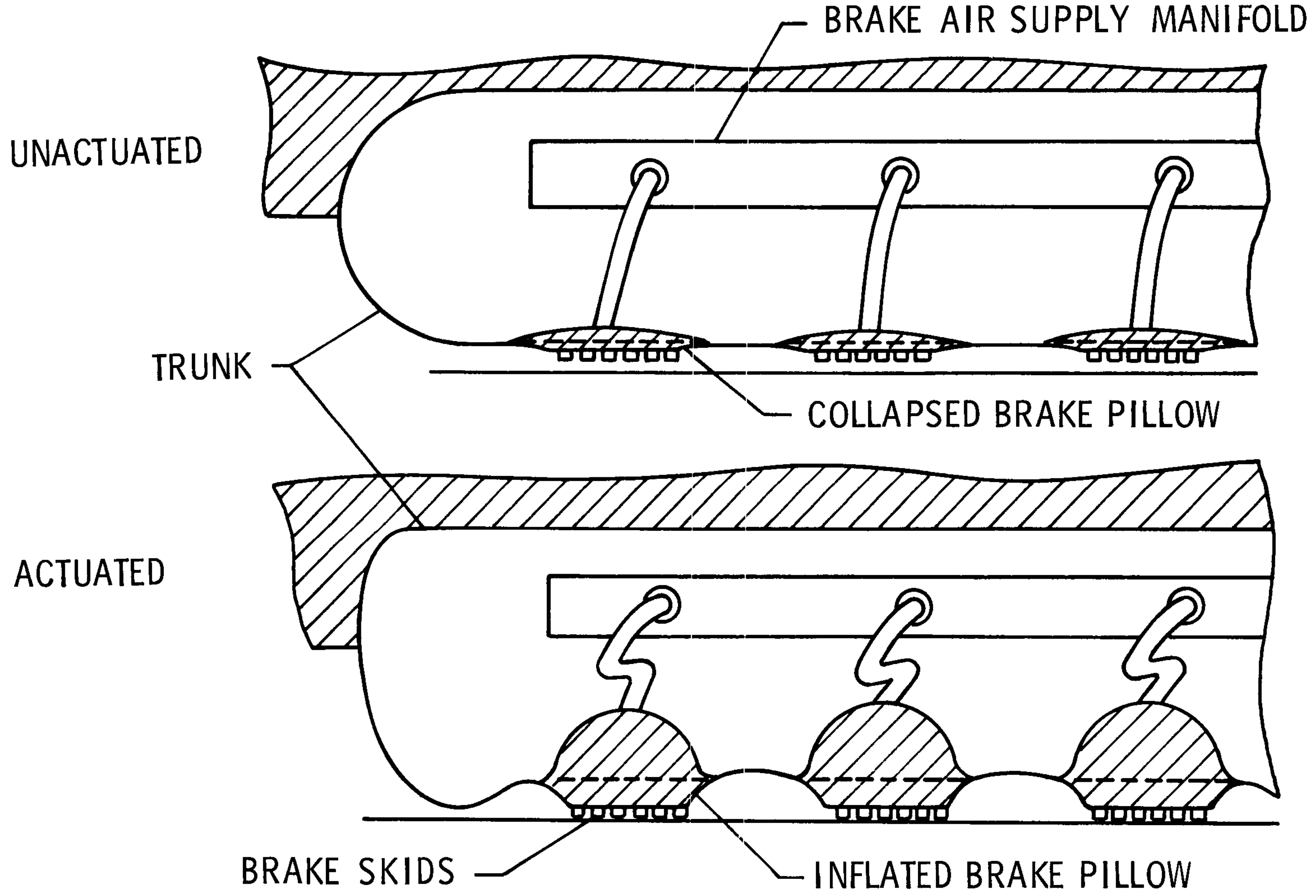
Slide 11

AIR-CUSHION LANDING SYSTEM - BRAKING

(Slide 12)

Braking of the ACLS is by inflatable skids as shown here. The skids, collapsed during take-off and flight as shown in the upper sketch, are pressurized during braking by their own air supply system to pressures higher than trunk pressure as shown in the lower sketch. The vehicle is steered by applying differential braking pressure to each side of the ACLS trunk.

BRAKING SYSTEM



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TYPICAL SHUTTLE AIR-CUSHION CHARACTERISTICS

(Slide 13)

A feasibility study of the ACLS applied to space shuttle booster and orbiter vehicles was conducted (ref. 4). The ACLS was shown to be both feasible and practical for shuttle applications. This slide shows the dimensions and operating pressures of two of the configurations studied, one for a booster and one for an orbiter. The booster ACLS is rectangular, and dimensions are for the system with the lowest footprint pressure (hence the largest system) studied. Only one orbiter configuration was studied, a triangular one. The study showed that materials are currently available which could be exposed to temperatures up to about 315° C (600° F) for as much as 100 hours and to about 425° C (800° F) for short periods of time and still function properly. Landing impact studies showed that landings at about 3 m/sec (10 ft/sec) would produce a total impact acceleration of about 1.5 g at the vehicle center of gravity. Trunk compression during landing was about 50 percent, which leaves additional stroke available to compensate for pilot error. Booster braking distances were computed for landing speeds of 120 knots and friction coefficients of 0.35 and 0.70. The distances calculated were about 600 m (1950 ft) and 330 m (1100 ft), respectively. The all-weather braking capability of skids would be maintained.

TYPICAL SHUTTLE AIR-CUSHION LANDING SYSTEM

	LENGTH, m	WIDTH, m	DEPTH, m	GROUND PRESSURE kN/m^2
BOOSTER	44	11	4	4.35
ORBITER	17	*8	3	8.70

* TRIANGULAR CONFIGURATION

FEATURES

300^0C TEMPERATURE CAPABILITY

1.5 g IMPACT ACCELERATION AT 3 m/sec SINK RATE

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WEIGHT COMPARISON – AIR-CUSHION SYSTEM AND CONVENTIONAL GEAR

(Slide 14)

One phase of the feasibility study was a weight comparison of the ACLS with conventional gear. This slide shows the ACLS weights computed, with adjustments made to conform to latest shuttle vehicle weight estimates, compared with conventional landing-gear weight estimates by Phase B contractors. With the ACLS, a total weight savings of 20 kN (4600 lb) for the booster and 11 kN (2500 lb) for the orbiter can potentially be realized. Based on a 1-to-6 payload weight savings for booster weight savings and a 1-to-1 savings for the orbiter, the total comes to about 5 percent of a 290 kN (65000 lb) payload. These weights include an air supply fan, motor, fuel, and thermal protection for the ACLS. Weight savings in fuselage structure were not computed, but distribution of the landing loads along the structure may yield considerable savings. These estimates are subject to the configurations studied and may be conservative or optimistic for any given configuration. The orbiter ACLS weight includes doors for thermal protection but the booster ACLS uses a protective layer. Doors may have to be added if later temperature estimates and materials studies show them necessary.

WEIGHT COMPARISONS

AIR CUSHIONS WITH CONVENTIONAL GEAR

	LANDING WEIGHT, kN	CONVENTIONAL GEAR WEIGHT kN	ACLS * WEIGHT, kN	SAVINGS, kN
BOOSTER	1957	83	62	21
ORBITER	934	47	36	11

* INCLUDES FAN, MOTOR, AND THERMAL PROTECTION

$$\text{PAYLOAD SAVINGS} = \frac{21}{6} + 11 = 14.5\ \text{kN} = 5\%$$

Slide 14

AIR-CUSHION LANDING SYSTEM - ADVANTAGES AND DISADVANTAGES

(Slide 15)

The potential advantages of the ACLS for shuttle vehicles are many. The potential weight savings may be a critical plus factor. The additional safety value of skid braking, water and rough-surface landing capability, and cross-wind landing capability cannot be minimized. The higher temperature exposure capability and distributed landing loads are important from a structural weight standpoint.

Primary disadvantages of the ACLS are that it requires considerable power (up to 2980 kW or 4000 hp) and it is a totally new concept which has never been applied to large aircraft. Emergency deployment can be accomplished by dynamic pressure during flight and initial touchdown but the most feasible solution at low speed would be to partially inflate the parking bladder at high speed and land on it with the skids to protect it. Finally, since the ACLS is a powered system and uses skids, it would require more maintenance than conventional systems.

AIR-CUSHION LANDING SYSTEM

ADVANTAGES

- POTENTIAL WEIGHT SAVINGS
- SAME WET-AND DRY-RUNWAY PERFORMANCE
- WATER AND ROUGH SURFACE CAPABILITY
- INHERENT CROSS-WIND LANDING CAPABILITY
- TEMPERATURE LIMITS ON MATERIALS HIGHER THAN WITH TIRES
- DISTRIBUTED STRUCTURAL LOADS

DISADVANTAGES

- REQUIRES POWER DURING LANDING
- NEW TECHNOLOGY
- EMERGENCY DEPLOYMENT AT LOW DYNAMIC PRESSURE
- MAINTENANCE

Slide 15

SUMMARY AND RECOMMENDATIONS

(Slide 16)

An overview of all the systems available for shuttle landing gear shows that the optimum system has not been found. Several new-technology systems may offer attractive advantages for shuttle applications in both operating and weight-saving considerations. With the stakes being rather high in this new breed of flight vehicle, it is inadvisable to ignore landing gear in conceptual design studies. An in-depth comparison study of landing-gear systems should be conducted before final commitments are made. Furthermore, the impact of landing-gear design on total system design including structural design, ground operations, and flight profiles should be assessed.

SUMMARY AND RECOMMENDATIONS

NEW TECHNOLOGY SYSTEMS MAY OFFER ATTRACTIVE OPERATING ADVANTAGES

WEIGHT SAVINGS MAY BE REALIZED WITH SOME NEW TECHNOLOGY SYSTEMS

IN-DEPTH COMPARISON STUDY OF LANDING-GEAR SYSTEMS IS DESIRABLE

IMPACT OF LANDING-GEAR DESIGN ON TOTAL-SYSTEM DESIGN SHOULD BE ASSESSED

Slide 16

REFERENCES

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