Complex Systems Collapse, Creative Destruction and Exaptive response: British Aviation in the 1930s

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Pierpaolo Andriani

Euromed Management, Marseille, France

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David Weir

University Campus Suffolk, Suffolk, UK

Our example

- Up to 1930 it was an even bet if Airships or heavier than air machines would emerge as the dominant design
- The UK Airship industry to early 1930’s…COLLAPSE
- The UK aviation industry from early 1930’s… Exaptative regeneration

R101

- *R101* was the result of a British government initiative to develop airships. In 1924, the Imperial Airways Scheme was proposed as a way to carry 200 troops or five fighter aircraft. This was expected to require an airship of 8 million cubic feet (230,000 m^3) – well beyond current designs. As a result, the two prototype airships of 5 million cubic feet (140,000 m^3) were authorized; two to exploit competition and develop new ideas.

R100 and R101

- Two teams were used: one, under direction of the Government Air Ministry would build *R101* (hence the nickname "the Socialist Airship"),
- the other by a private company, Vickers, building R100(the "Capitalist Airship") under contract for a fixed price.
- Among Vickers' engineers were the designer Barnes Wallis later famous for the bouncing bomb and, as Chief Calculator (ie, Stress Engineer), Nevil Shute Norway better known as the novelist Nevil Shute.

R101 at the mast at Cardington

R100 en route to Canada

The R100: model

The disaster

- Shortly after 02:00 AM on the morning of Sunday October 4, 1930, the pride of the British Government's aviation strategy, the giant airship R101, crashed into a low hill near Beauvais in Northern France and burned out, killing all but eight of its passengers and crew, including the Secretary of State for Air, whose department had overseen the design and construction of the airship and who was on his way to India to take over the post of Viceroy.

Political and industrial catastrophe

- To British engineering, aviation and imperial interests this was in its day an event of monumentally catastrophic significance, ranking with the Challenger disaster or with 9/11 in the immediacy of its impact and the far-reaching implications of the strategic decision-making that stemmed from it. This was a political, technological and organisational disaster.

Private enterprise v Civil Service

- The essential design of the R101 was tried and tested and the sister airship, the R100 had just recently flown successfully across the Atlantic to Canada and back.
- But the R100 had been built by a private enterprise organisation, of which the prime investor had been the Vickers company.
- The doomed R101 was built by a government enterprise and decision-making had been essentially undertaken on civil service principles

Hydrogen or Helium?

- The explosion of the 5,500,000 cu. ft. of hydrogen inflating the R-101 caused practically all the devastation.
- If non-inflammable helium (gas next lightest to hydrogen) had been used the R-101 would not have exploded.
- British commentators had already noted this obvious fact, with the implication that the U. S., monopolist of the world's helium supply, had selfishly prevented any of the gas from being exported.
- President Hoover deemed this insinuation worthy of White House denial.

Why?

- Adverse weather conditions

- Overweight: Poor Lift/Weight ratios
- The R101 was meant to have a useful lift of 60 tons but ended up only able to carry 35 tons

- Construction failures

Soft Signals of impending disaster for the R101

- The stability of *R101* was doubtful, due to the insufficient span of its fins into the airstream. During its flight at the Hendon air show in 1930, it almost plunged to the ground, as well as repeatedly going into a dive during the return flight.
- The internal gas bags rubbed against the frame causing rupture and leakage
- The gas bag valves were of a novel design and placement and showed a tendency to open slightly as the ship rolled thus causing a continual leaking of lifting gas and leading to constant decrease of lift in flight.
- The doping of the skin material caused cracking leading to ruptures
- The internal gas bags rubbed against the frame causing rupture and leakage
- Engine problems: the big end bearings were also found to be prone to early failure, and it was reported gold plating had to be used to lengthen their life. In additions, there were two critical vibration frequencies which coincided with idling and cruising speeds.
-
- ***Despite all this, it was given a Certification of Airworthiness just before lift off***

Political framework

- Economic difficulties
- Government prestige implicated in Airship project
- R100 had just returned from a successful maiden flight to Canada
- Viceroy of India and previous Air Minister Lord Thomson was to be carried in triumph to India on the maiden voyage of R101

Rush, Rush…More haste, Less Speed!

- The Air Ministry pressured the engineers to finish the project. The final trial flight of *R101* was originally scheduled for September 26 1930 but an unfavourable wind delayed it until October 1
- She returned to Cardington after a flight of 17 hours.
- *R101* departed on October 4 at 6:24 p.m. for its intended destination to Ismailia and Karachi

The flight

- The airship had to drop 5 tons of water ballast to lift off.
- Over France, *R101* encountered gusting winds that tore back the outer covering, exposing and rupturing the first gas bag.
- *R101* crashed into a hillside near Beauvais, north of Paris, at only 13 mph (20 km/h).
- The crash ignited the leaking hydrogen and fire quickly engulfed the entire airship.
- Forty-six of the fifty-four passengers and crew were killed immediately.
- Two men who survived the crash later died at the hospital bringing the total to forty-eight dead.

The midnight message

- 2400GMT 15 miles SW of Abbeville speed 33 knots. Wind 243 degrees [West South West] 35 miles per hour. Altimeter height 1,500feet. Air temperature 51degrees Fahrenheit . Weather - intermittent rain. Cloud nimbus at 500 feet. After an excellent supper our distinguished passengers smoked a final cigar and having sighted the French coast have now gone to bed to rest after the excitement of their leave-taking. All essential services are functioning satisfactorily. Crew have settled down to watch-keeping routine."

Last moments

- At 02.00am the ship made a long and rather steep dive, sufficient to make the engineers lose balance and cause furniture in the smoking room to slide. It is estimated that a rent occurred in the rain soaked upper part of the nose, causing the forward gas bags to become exposed to the elements and damaged by the gusting wind. The loss of gas at this point could have led to the loss of control of the ship. Also, the ship was travelling towards the notorious Beauvais ridge which was well know by aviators for its dangerous gusting wind. The loss of gas at the forward part of the ship, combined with a sudden downward gust of wind would have forced the nose down. Calculations by the University of Bristol in 1995 provided evidence that the maximum downward angle was 18 degrees in this first dive through a time span of 90 seconds.

Last seconds

- The crew in the control car would have tried to correct the downward angle by pulling the elevator up. In the next 30 seconds, the ship pulled out of the forced dive and the crew were steadying the ship. Flying at a nose-up angle of three degrees enabled the ship to regain some aerodynamic stability. However it was realised that the elevator was "hard up" and yet the crew knew that the nose was only three degrees above the horizon. This meant that the nose was now extremely heavy and hence a serious loss of gas from the forward bags must have occurred.

"We're down lads".

- The Captain then rang the order for all engines to reduce speed from the original cruising speed, if not to stop them. The bells were heard and acted upon by the crew as evidence from the survivors confirmed. Chief Coxswain Hunt moved aft from the control car to the crew's quarters. At this point he passed crew member Disley, and warned "We're down lads". This famous comment by one of the most experienced airship crew members showed that the R101 was not going to be able to continue and that an executive decision had been made to make an emergency landing.

The ship moved into a second dive

- It is calculated that R101 was now at a height of about 530 feet, which for a vessel of 777 feet long was precarious. Rapid oscillation of the ship had already occurred and any further oscillation would cause it to fail. Rigger Church was ordered to release the emergency ballast from the nose of the ship and was on his way to the mooring platform when he felt the angle of the ship begin to dip once more from an even keel. The ship began to drop again through a downward angle and at this point the nose hit the ground.

The burnt out skeleton of R101

Consequences

- The Airship programme was killed
- The “industry” “collapsed”
- The decisive turning-away in Great Britain from what may have turned out to be a technological blind alley. Concentration on Aircraft like Spitfire fighter, Wellington bomber
- In Germany inventive capability, personnel, materiel and funding was split between airship and aircraft design for a further seven years until the even more spectacular destruction at Lakehurst USA of the Hindenburg Airship. This inhibited the development of the ME 109
- Geodesic principles of R100 built into the successful Wellington bomber

Longer term impact

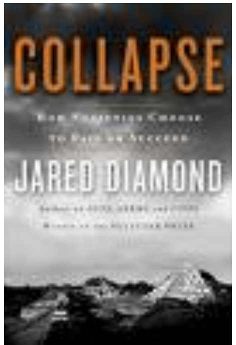
- R100 broken up: materials sold for scrap: duralumin metal bought by Zeppelin for their airship programme
- Airplanes preferred to airships in UK programme
- Government intervention in Industry discredited for a generation
- Skills of participants like Nevil Shute Norway recycled into aircraft industry

Short analysis of collapse

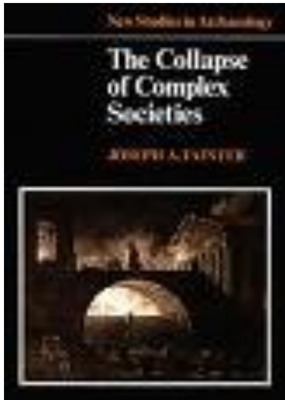
Collapse: definition

- "***A society has collapsed when it displays a rapid, significant loss of an established level of sociopolitical complexity***"(Tainter, 1988) p4).

- "*a complex society that has collapsed is suddenly smaller, simpler, less stratified, and less socially differentiated. Specialization decreases and there is less centralized control. The flow of information drops, people trade and interact less, and there is overall lower coordination among individuals and groups. Economic activity drops to a commensurate level, while the arts and literature experience such a quantitative decline that a dark age often ensues. Population levels tend to drop, and for those who are left the known world shrinks*" (Tainter, 1988) p. 193).



Loss of diversity and loss of connectivity



Collapse and recovery

- Literature on collapse, highly specialised and often discipline restricted (Diamond, Tainter, Gibbon, Erwin, Benton, etc)
- Literature on the origin of systems is extensive but disconnected with collapse
- Literature on recovery after collapse is almost non existent

  "*I can now confess that as an evolutionary biologist, understanding the recovery after the extinction poses a far greater intellectual challenge. Sadly few of my colleagues seem to share this perspective, and recoveries after mass extinction have attracted far less attention than the extinctions themselves. In part this reflects a persistent bias that there is* ***nothing particularly unique about biotic recoveries*** *deserving of study: the extinction over, the survivors become fruitful and multiply, and that's that*"

  and

  "*most models of mass extinction assume that extinction is a giant hand sweeping pieces off the board,* ***but leaving the board and the rules of game intact***" (Erwin, 2006: 219)

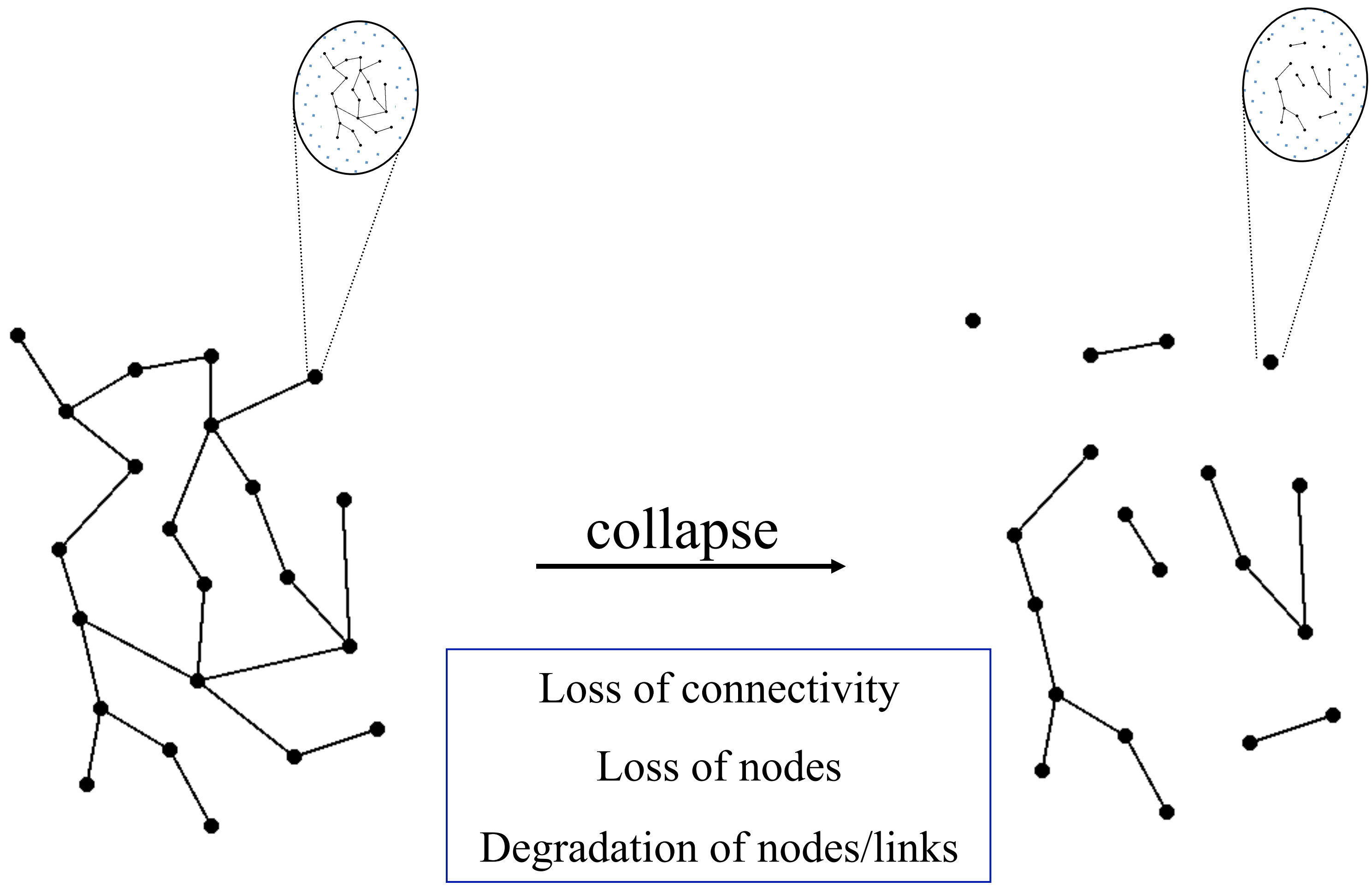
The view that Erwin criticises

- Implies:
  - long recovery time due to gradualism and linearity
  - greenfield assumption
  - that recovery is often due to injection of exogenous resources

- Ignores or downplays:
  - quick rebound of systems after collapse due to reconversion

- In particular:
  - Ignores recombinant mechanisms and exaptations

Collapse and network representation



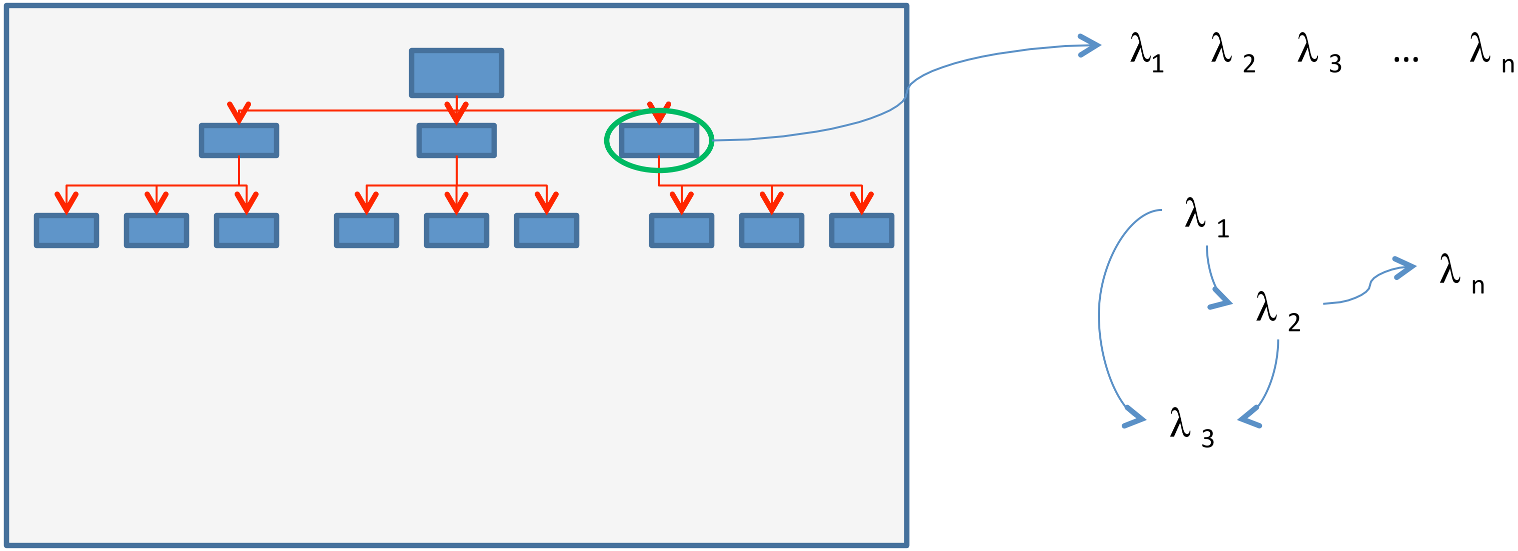
Λ-knowledge and Ω- knowledge

- For Mokyr (2002) technical knowledge has two elements:
  - Λ-knowledge: recipe (if-then statements)
  - Ω- knowledge: beliefs about applicability of Λ-set

- Knowledge can be experience-based—hence context dependent—or abstract.

- Experience-based knowledge is local. It follows that context constrains applicability (path-dependency) and that range of applicability is non pre-statable (Kauffman, 2000)

Technologies form nested systems (Arthur, 2009)



λ_i depends on:

1. Ω- knowledge: beliefs about applicability of Λ-set
   If Ω is experience-based (limited or no abstraction) then its validity is local: then λ is context-dependent as well. This implies that
2. λ is partly defined by the relational structure of the set of other techniques $\lambda_{j:1\dots m}$ with which it interacts (where m is number of techniques interacting with λ_i , which includes horizontal, nested and nesting interactions)

A collapse causes

- The extinction of the architecture of techniques.
  - Selection is skewed towards more complex techniques characterised by multiple nested levels
  - Survival is skewed towards less complex techniques

- <u>BUT</u> if techniques are context-dependent, then collapse transforms surviving techniques.

- Surviving techniques are different because:
  - Fragmented: less connected to dominant architecture
  - Less fine-tuned to specific markets and socio-technical applications
  - More 'exaptable'
  - More recombinable

Exaptation

Definition

- **“We suggest that such characters, evolved for other usages (or for no function at all), and later “coopted” for their current role, be called *exaptations*”** (Gould and Vrba, 1982).

- “Refers to cases in which an entity was selected for one trait but eventually ended up carrying out a related but different function” (Mokyr, 1998).

- "The later exploitation in a new context of an acquisition originally made in another entirely (Tattersal, 1998).

Exaptation, adaptation and aptation

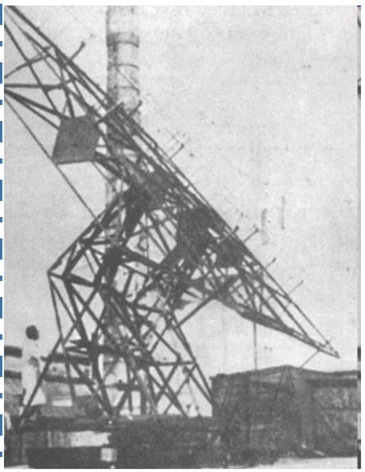
TABLE 1. A taxonomy of fitness.

<table>
<tr><th>Process</th><th colspan="2">Character</th><th>Usage</th></tr>
<tr><td>Natural selection shapes the character for a current use—adaptation</td><td>adaptation</td><td rowspan="3">aptation</td><td>function</td></tr>
<tr><td>A character, previously shaped by natural selection for a particular function (an adaptation), is coopted for a new use—cooptation</td><td rowspan="2">exaptation</td><td rowspan="2">effect</td></tr>
<tr><td>A character whose origin cannot be ascribed to the direct action of natural selection (a nonaptation), is coopted for a current use—cooptation</td></tr>
</table>

Gould and Vrba (1982), "Exaptation – a missing term in the science of form", *Paleobiology*, vol. 8, N. 1, p.5

The "invention" of the microwave oven

From a radar system



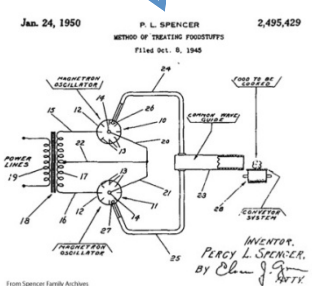
http://www.youtube.com/watch?v=4h1ESUz2H3E&feature=player_detailpage

http://en.wikipedia.org/wiki/Mr._Goodbar

To the microwave industry

Evolution of microwave industry

1945 1947 1960s 1967 1971 1970s 1976 1994



Patent

Discovery

Dominant design?

In the 1960s, [Litton](#) bought [Studebaker](#)'s Franklin Manufacturing assets, which had been manufacturing magnetrons and building and selling microwave ovens similar to the Radarange. Litton then developed a new configuration of the microwave, the short, wide shape that is now common. The magnetron feed was also unique. This resulted in an oven that could survive a no-load condition, or an empty microwave oven where there is nothing to absorb the microwaves.
wikipedia

Early majority?

Introduced in 1967, the Amana Radarange microwave oven would forever change the way American families prepare meals. http://www.smecc.org/microwave_oven.htm

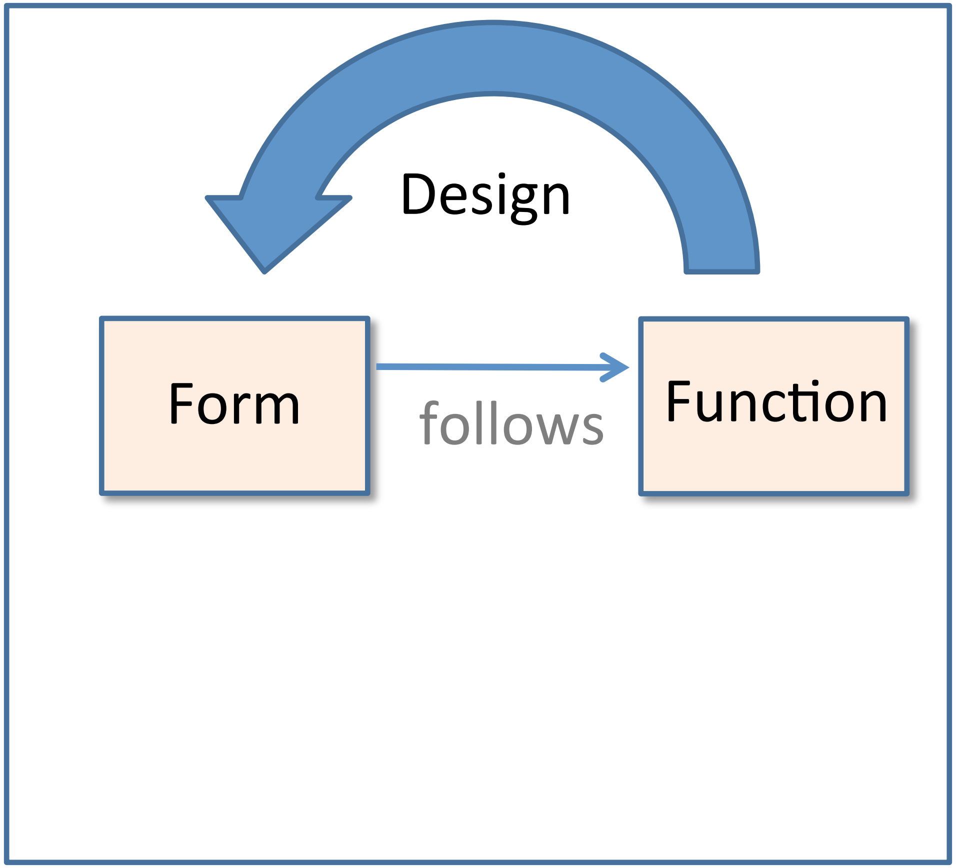
Standards and regulations set by the federal government fixed previous problems with microwaves leaking out of microwave ovens.

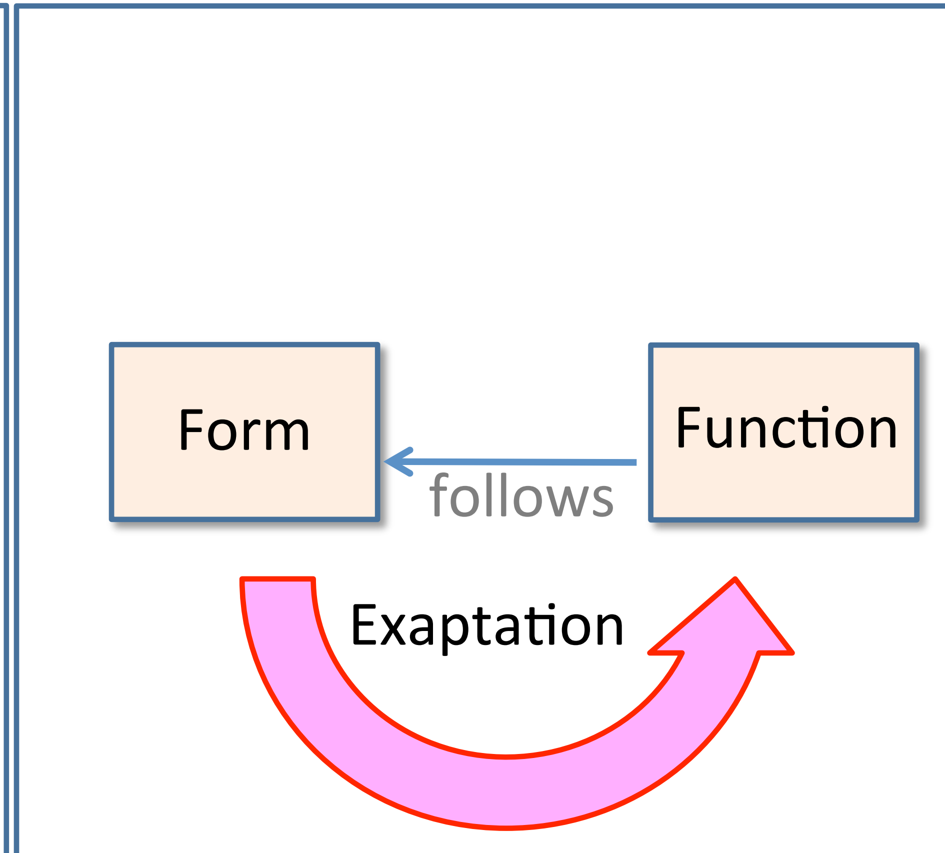
- Users' innovations
- Emergence of myths (MW leads to infertility, etc.)
- Massive diversification

52 millions MW oven sold

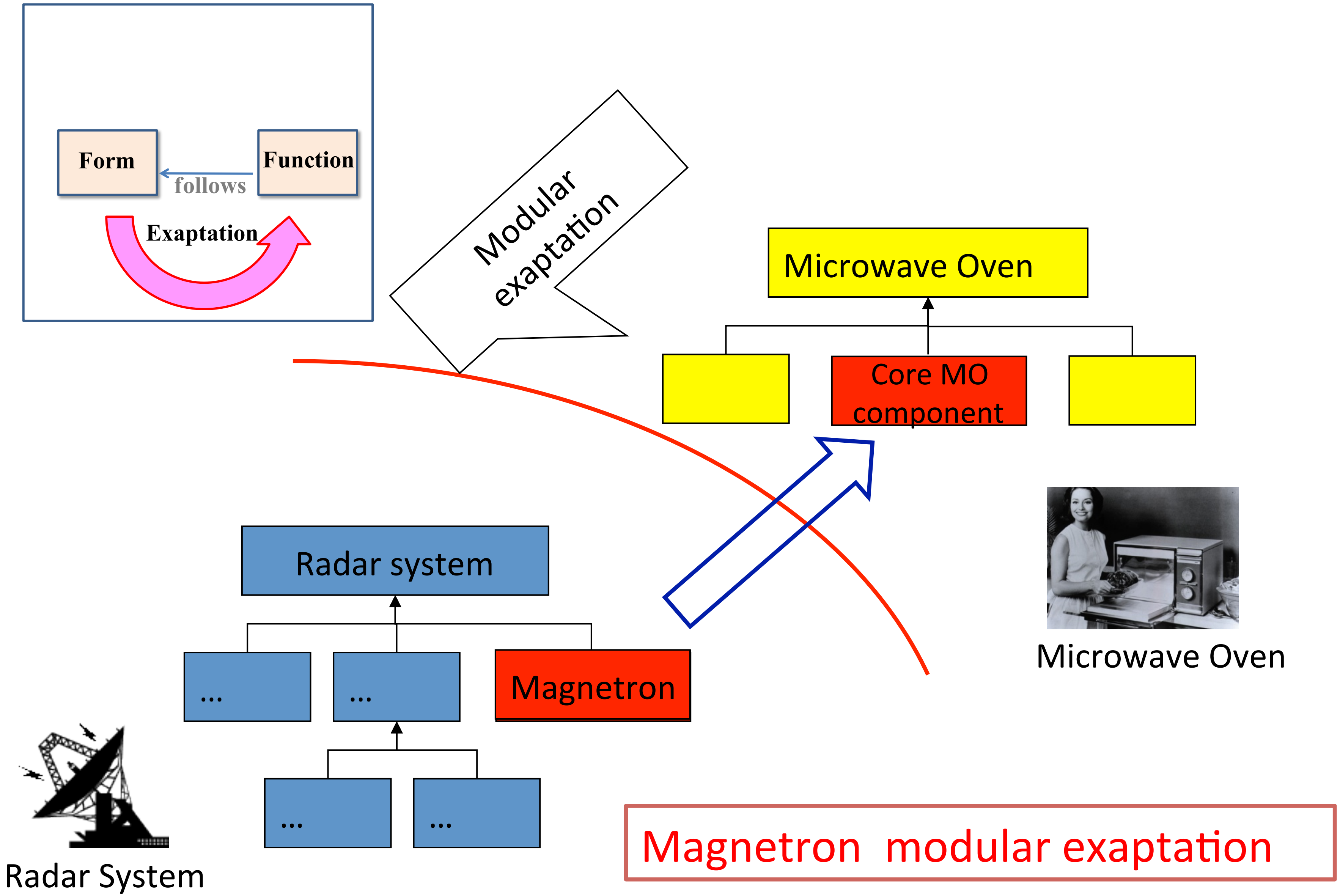
92% of US household have a MW oven

The synthesis of the form...





Modular exaptation mechanisms: horizontal transfer



Impact of collapse on search processes

- Carriers of techniques forced to search for related applications in an expanded search landscape, outside their 'natural' environment.
  - Before collapse search is dominated by network of interdependencies within dominant architecture. This constrains search within the dominant socio-technical architecture.
  - After collapse search happens predominantly outside of socio-technical architecture in which techniques were designed. Therefore, search after collapse may lead to applications that are technologically conservative (i.e. applications that are based on market-discontinuity and technological continuity). This may lead to exaptation of capabilities.
  - After collapse, deconstraining of techniques generates more opportunities for recombinant dynamics.

Two principal players
Barnes Wallis and Nevil Shute Norway

Three core technologies to follow

- Streamlining and Laminar airflow

- Geodetic structure

- Light aluminum metals

Barnes Wallis

- Barnes Neville Wallis was born the son of a doctor on 26 September 1887 in Ripley, Derbyshire. Wallis worked first at a marine engineering firm and in 1913 he moved to Vickers, where he designed airships, including the R100. In 1930 Wallis transferred to working on aircraft. His achievements included the first use of **geodesic design in engineering**, which was used in his development of the Wellesley and Wellington bombers. When World War Two began in 1939, Wallis was Assistant Chief Designer at Vickers Aviation section.
- In February 1943, Wallis developed a drum-shaped, rotating bomb that would bounce over the water, roll down the dam's wall and explode at its base. ***The "bouncing bomb" of "The Dambusters"***
- When the decision was taken to concentrate on area bombing, Wallis began looking at the design of aircraft that could drop heavy bombs. The adapted Avro Lancaster was able to drop two bombs developed by Wallis, the 'Tallboy' designed in 1944 and the 'Grand Slam' from the following year. Both were used against heavily fortified German targets. The "ground-shaking" concepts of these designs are the basis of the current generation of **"bunker-busting" bomb technology**
- After the war, Wallis led aeronautical research and development at the British Aircraft Corporation until 1971

The Vickers Wellington:11,461 built

- The Vickers Wellington was a two-engined bomber capable of carrying 4,500 pounds of bombs, slightly more than early model B-17E Flying Fortresses, though it was far less well defended.
- The Wellington's geodesic structure, pioneered by Barnes Wallis of Dambuster bomb fame, was immensely strong and able to absorb terrific damage

.

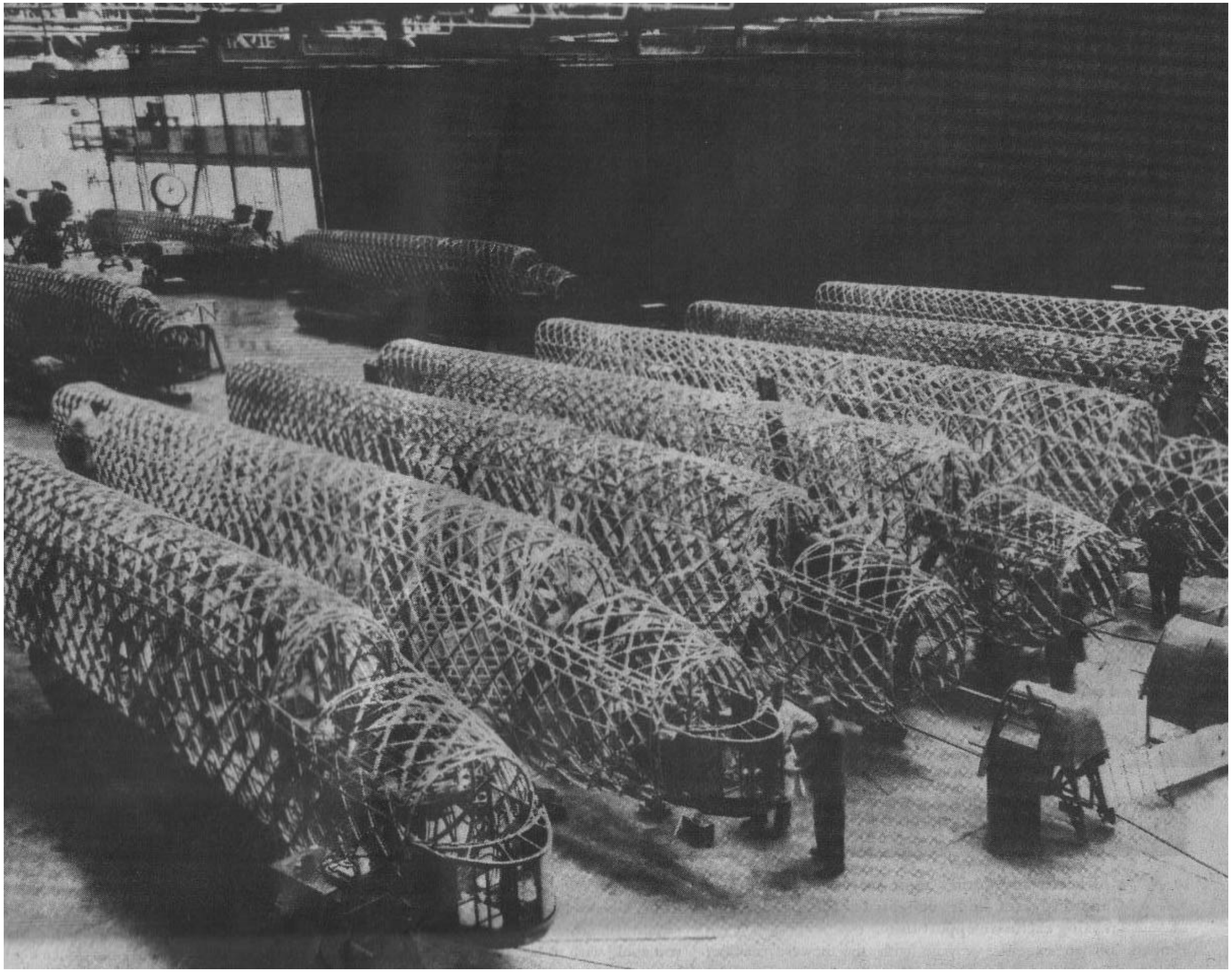
Wellington bomber: you can see the characteristic criss-cross bracing behind the cockpit

Wellington bombers in production

- The fuselage was built up from a number of light alloy channel-beams that were formed into a large network. This gave the plane tremendous strength because any one of the stringers could support some of the weight from even the opposite side of the plane.
- Blowing out one side's beams would still leave the plane as a whole intact. Wellingtons with huge holes cut out of them continued to return home when other planes would not have survived.

Wellington fuselages in construction

- Geodesic structure



A Vickers Wellington Bomber after a Problem with German Flak that nonetheless returned safely to its UK base.

The bouncing bomb

The Bouncing bomb

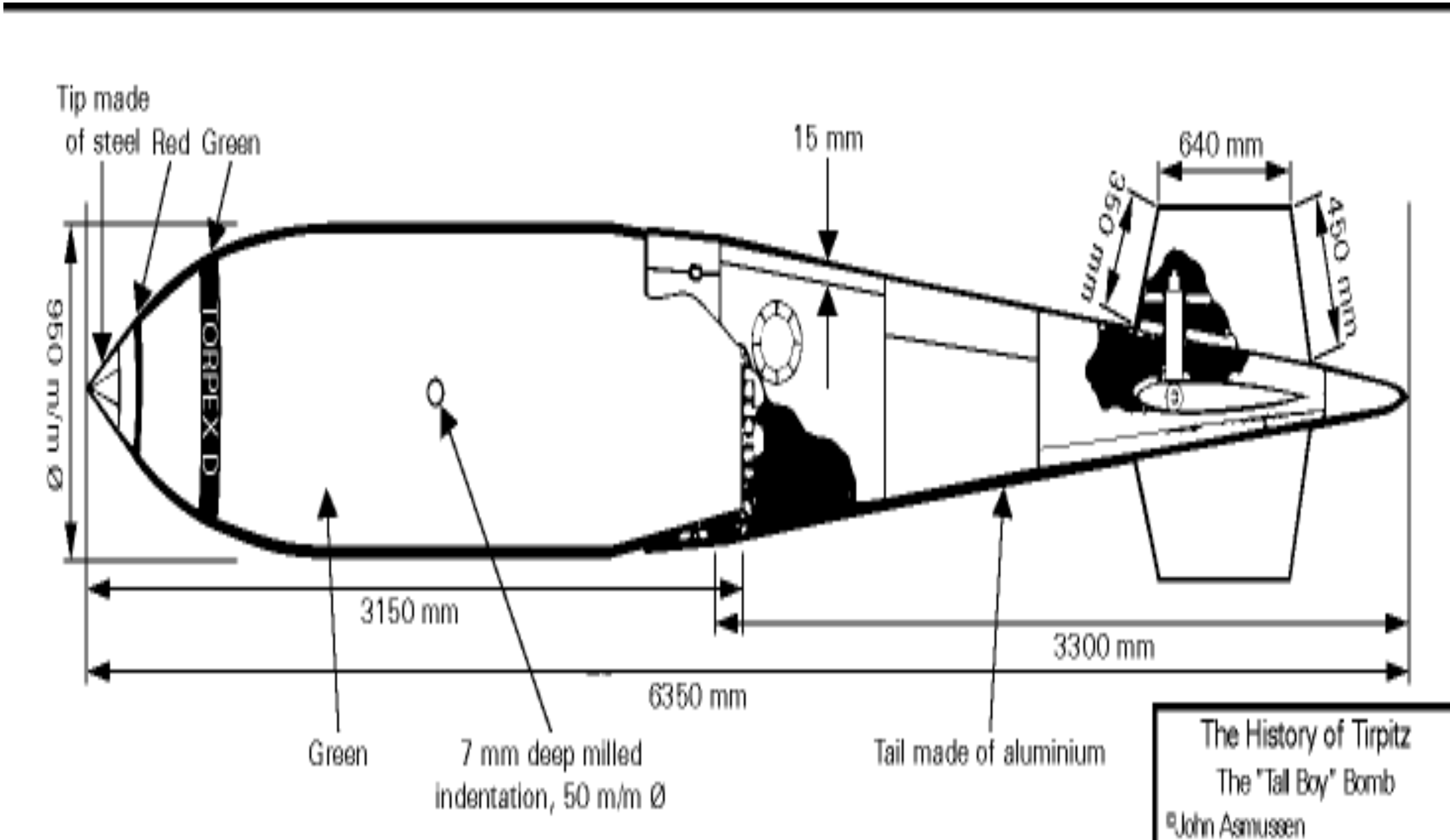
The bouncing bomb

- It didn’t just “bounce” like a skipping stone
- It rotated forward, spinning
- At the end of the reservoir it sank against the dam wall
- It then exploded underwater

The aerodynamic bomb

- To achieve ground penetration to obtain the earthquake effect, Wallis designed the Tallboy to be very aerodynamic so that when dropped from a great height it would reach a velocity higher than traditional bomb designs. In the final design the tail of the bomb was about half the overall length of the finished weapon — the bomb casing was some 10 feet (3.05 m) of the overall 21 foot (6.35 m) length. Initially the bomb had a tendency to tumble, so the tail was modified — the fins were given a slight twist so that the bomb spun as it fell. The gyroscopic effect thus generated stopped the pitching and yawing, improved the aerodynamics and improved accuracy. The improved design worked so well that it was found in development that it passed through the sound barrier as it fell.

Tallboy



The British "Tall Boy" was among the heaviest bombs of World War II. It was outweighed only by the almost ten-ton "Grand Slam" which was not used against naval targets. The Tirpitz was conquered by "Tall Boys".

Laminar Air Flow

- **Laminar flow**, occurs when a fluid flows in parallel layers, with no disruption between the layers. It is the opposite of turbulent flow.
- In nonscientific terms laminar flow is "smooth," while turbulent flow is "rough."
- For example, consider the flow of air over an airplane surface. The boundary layer is a very thin sheet of air lying over the surface of the wing (and all other surfaces of the airplane). Because air has viscosity, this layer of air tends to adhere to the wing. As the wing moves forward through the air, the boundary layer at first flows smoothly over the streamlined shape of the airfoil. Here the flow is called *laminar*.
- Barnes Wallis was especially concerned to improve the laminar flow over the airship surface by streamlining.

Laminar Flow, swing-wing and TSR2

- Though he did not invent the concept, Wallis did much pioneering engineering work to make the swing-wing concept functional. His early "Wild Goose", designed in the late 1940s, hoped to use laminar flow, but when this was shown to be unworkable, he developed the swing-wing further for the "Swallow", designed in the mid-1950s, which could have been developed for either military or civil applications.
- On UK government instructions, however, Vickers passed the swing-wing designs to the US Government and instead adopted the BAC TSR2 (on which one of Wallis' sons worked) and Concorde. Wallis was quite critical of the BAC TSR-2, stating that a swing-wing design would be more appropriate and demonstrating the concept by flying scale models without tailplanes.
- In the mid-1960s, The BAC TSR-2 project was ignominiously scrapped in favour of the American F111– which had swing wings based on Wallis's work – though this order was also subsequently cancelled.

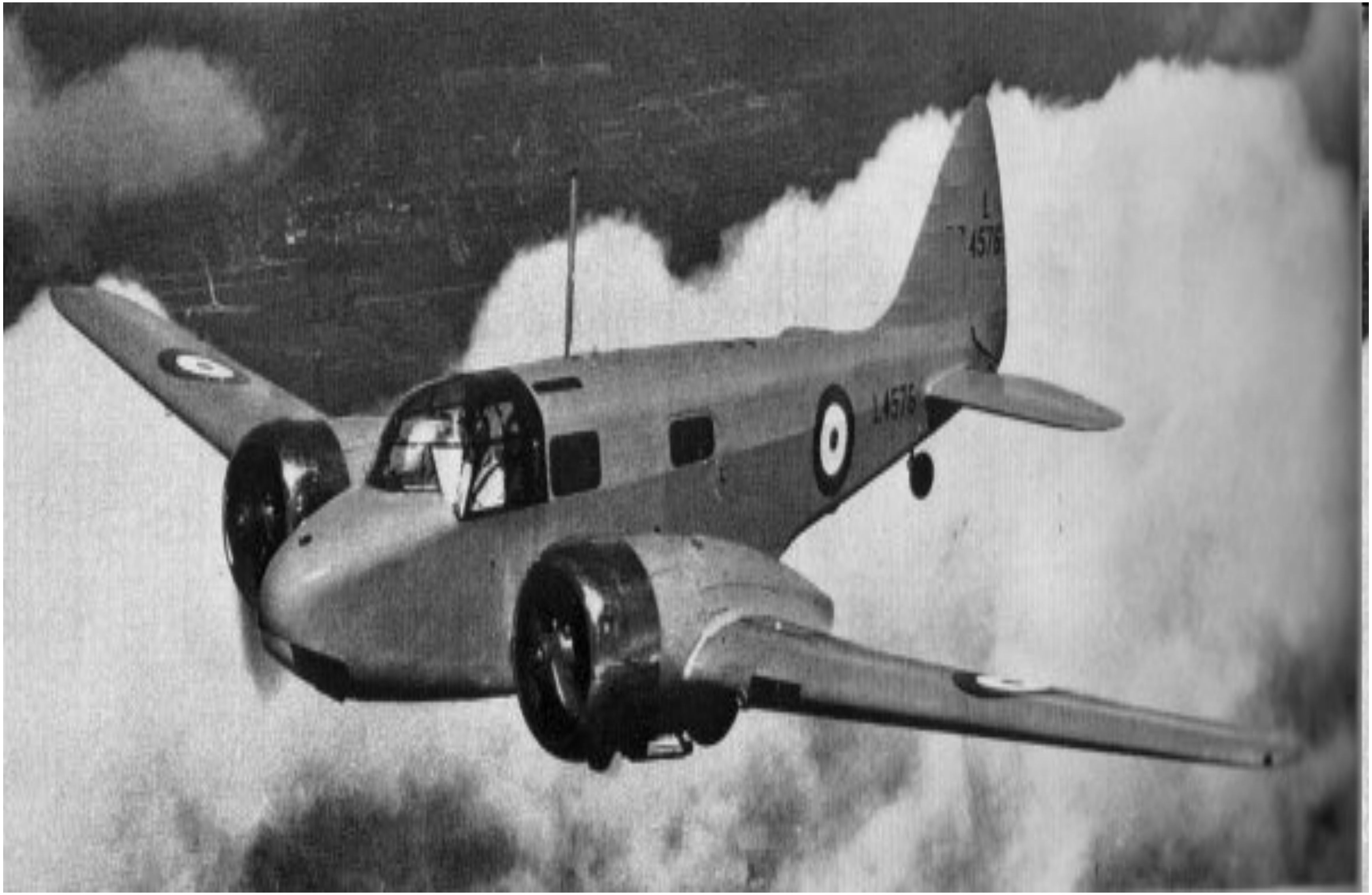
Nevil Shute Norway and Airspeed

- NSN and Hessell Tiltman founded Airspeed company in Bus garage in York
- NSN raised money from Yorkshire landowner Lord Grimthorpe after failing to raise funds in the City or from government
- Airspeed Limited formed - 13th March, 1931
  Original Directors - N.S.Norway, A.Hessell Tiltman, Lord Grimthorpe, Sir Alan J.Cobham and A.E.Hewitt.
- Moved to factory at Portsmouth municipal airport
- Broke gliding records to get name established
- Patents on retractable undercarriage and in-flight refuelling
- Designed Envoy for Kings Flight; Courier and Oxford for RAF

Nevil Shute Norway

- Became best-selling author of blockbusting books like
- Pied Piper
- A town like Alice
- No Highway
- On the Beach
- All of these became big Hollywood movies
- Worked in WW2 on top secret rocket and weapons research
- Emigrated to Australia in 1951

Airspeed Oxford



Airspeed Oxford became the RAF's chief bomber trainer: 8751 were built

Airspeed Oxford

- The Oxford first appeared in 1937 as a military development of the 1934 Envoy and was the first twin-engined monoplane trainer in the Royal Air Force. the first Oxfords joined the Central Flying School in November 1937, and by the time of the outbreak of World War 2 nearly 400 were in service. Production was subsequently stepped up, Airspeed building nearly four and a half thousand Oxfords, and with sub-contracts placed with de Havilland, Percival and Standard Motors the total number of Oxfords completed came to 8751.
- Although used most widely in its intended role as aircrew trainer, the Oxford gave valuable service on communications and anti-aircraft co-operation duties, and was also used in some numbers as an ambulance, particularly in the Middle East. As a trainer, it served in Canada, Australia, New Zealand and Southern Rhodesia as well as in the United Kingdom.

Materials

- **Duralumin** is the trade name of one of the earliest types of aluminum alloy eg AA2024, which contains (in wt.%) 4.4% copper, 1.5% magnesium, 0.6% manganese and 93.5% aluminium
- Duralumin was developed at Dürener Metallwerke Aktien Gesellschaft 1903-1909
- Its first use was rigid airship frames. Its composition and heat-treatment were a wartime secret.
- Duralumin quickly spread throughout the aircraft industry in the early 1930s
- Duralumin also is popular for use in precision tools such as levels because of its light weight and strength.
- ***Strong, light, ductile, heat-resisting***

Exaptation ***The later exploitation in a new context of an acquisition originally made in another context entirely (Tattersal, 1998***)

- Re-cycling of design principles
- Streamlining and Laminar airflow
- Geodetic structure
- Materials
- People and agency
- Knowledge transfer
- Community of practice

Models of technological change

- Creation of new science/ technology (*innovation as invention* model)
- Transfer from one use to another (*innovation as transfer* model)
- Design of new architectures based on re-configuration of existing modules (*recombinant innovation or ‘brokering’* model)
- Re-incorporation of specific elements of design into new un-planned and un-expected configurations (exaptative response)

* Too reliant on “great inventor” concept
* Too dependent on inter-dependent communities of practice concept
* Too dependent on “design” concept
* Ex-aptation more consistent with biological and other systems experience

Airships: the air cargo vehicle of the future?

- http://roomfordebate.blogs.nytimes.com/2010/04/22
- /the-new-age-of-travel-blimps-and-beyond/

Conclusions

1. We interpret collapse as the rapid disappearance of a socio-technical architecture

2. Continuity with past provided by techniques not architecture

3. Reconfiguration of techniques may cause emergence of new technological architectures

4. Innovation mode after collapse shifts to architectural via recombinant and exaptational mechanisms

5. Regeneration from the ashes may happen rapidly and in completely different market segments

Conclusions

The dynamics of innovation processes in collapsed systems might be qualitatively different from innovation during expansionary periods

Final thoughts

- **“Life creates order, but order does not create life”**
- **(Antoine de St Exupery: Letters to a Hostage, 1942)**

- **“Stuff happens”**
- **(Donald Rumsfeld: Saturday, April 12, 2003)**